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by

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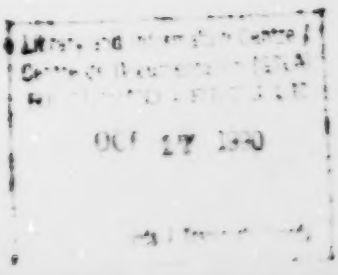

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16 Abstract

To support the operation of the CCG Ice breakers it has been proposed to put reconnaissance systems on the helicopter and also to telemeter the data back to the ship. This study addresses the optimum type of active sensor to place on a helicopter. Three types of radars were studied, a Synthetic Aperture Radar (SAR), a real aperture Side Looking Airborne Radar (SLAR) and a Rotating Antenna Radar (PPI). The study was based on simulations using fine resolution SAR data collected using the INTERA STAR-1 system, flown at high (9000 m) altitude. To do this a model of ice reflectivity was evolved based on a combination of published data, and a single trial data set that had been collected with STAR-1 flown at 1500 metres. Imagery was simulated for altitudes of 300, 1000, and 3000 metres.

The simulations show that, for helicopters flown at normal altitudes of 1000-3000 metres, SAR systems do not give substantially better information at far ranges than do SLAR systems. This is due to the dominating effect of the fall-off in ice reflectivity at shallow angles. PPI type radars also give rather good quality imagery, compared to SARs, when restricted to close ranges, and low altitudes. Either a SLAR or a PPI would give excellent imagery over a swath width of 10 km from 1000-3000 metres altitude. The report concludes that, to further specify the optimum system, a study of the detailed requirements of the CCG be undertaken, using a helicopter-mounted radar.

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16. Résumé

A l'appui des opérations des brise-glace de la Garde côtière canadienne, il est proposé d'équiper les hélicoptères de ces navires de capteurs de reconnaissance des glaces et de systèmes de télémétrie. La recherche avait pour but de trouver le capteur héliporté à circuits actifs le plus apte à cet usage. Trois radars ont été comparés: à ouverture synthétique (ROS), à visée latérale (RVL) et à écran panoramique (PPI). Comme base pour cette étude comparative, les chercheurs se sont servis des signaux du radar à ouverture synthétique et à haute résolution à bord du Star-1 de Intera volant à 9 000 m d'altitude. A cette fin, la réflectivité des glaces a dû être modélisée à partir de données connues et d'autres obtenues à l'aide du Star-1, à 1 500 m d'altitude cette fois. Les altitudes auxquelles les images de synthèse devaient correspondre ont été 300, 1 000 et 3 000 m.

Les simulations ont montré que l'information transmise par les ROS fonctionnant aux altitudes habituelles d'un hélicoptère, 1 000 - 3 000 m, n'est pas sensiblement supérieure à celle transmise par les RVL aux grandes distances-sol. L'explication réside dans l'effet prédominant de la perte de réflectivité des glaces aux angles étroits. Quant aux PPI, l'information qu'ils transmettent, comparée aux ROS, est relativement bonne, mais seulement aux distances-sol et aux altitudes peu élevées. Lorsque le couloir à balayer a 10 km de large et que l'altitude se situe entre 1 000 et 3 000 m, l'information transmise par les RVL et le PPI est également bonne. Afin de mieux définir le capteur optimal, le rapport propose un programme expérimental qui, faisant appel à un radar héliporté, permettra à la GCC de mieux cerner les aspects essentiels auxquels il faudra satisfaire.

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SUMMARY

To support the operation of the CCG Ice breakers, helicopter ice reconnaissance missions are often flown with the ship's support helicopter. To improve the quantity and quality of information available to the ship's crew, it has been proposed to put reconnaissance systems on the helicopter and also to telemeter the data back to the ship. There have been two studies of the problem of optimizing the sensor to be placed on the helicopter. The first study by Ramseier concluded that the optimum sensor would be a microwave imaging system, based on either passive or active technologies. This second study addresses the optimum type of active sensor to place on a helicopter.

Three types of radars were studied, a Synthetic Aperture Radar (SAR), a real aperture Side Looking Airborne Radar (SLAR) and a rotating antenna radar (PPI). The study was based on the use of fine resolution SAR data collected using the INTERA STAR-1 system, flown at high (9000 m) altitude, to simulate the imagery that would be obtained with the chosen radar at a lower altitude. To do this a model of ice reflectivity was evolved based on a combination of published data, and a single trial data set that had been collected with STAR-1 flown at 1500 metres. Imagery was simulated for altitudes of 300, 1000, and 3000 metres, which are altitudes that represent the lower and higher bounds and probable operating altitudes of helicopters.

The simulations used are only approximate, and in the absence of a better ice classifier, there will be errors in the treatment of some ice features. However, the overall effects are quite reasonable, and provide a graphic display of the results of flying at lower altitudes. By calibrating the simulation with the SAR data at 1500 m altitude, and with marine radar imagery (not of the same area), a good representative simulation has been obtained.The simulations therefore represent a suitable means of limiting the amount of flying to be done to conduct preliminary tests of the different styles of radars.

SAR Simulations

Using these data as a basis for discussion, some observations can be made on the potential utility of a helicopter borne SAR. Because the ice reflectivity is such a strong function of angle, the far edges of the image, with a STAR-1 type SAR flown at altitudes of 1000 metres or less, will contain little but information on ridges. Since ridges have their own angle, the angle of incidence between the ice and radar is much less than that for the undeformed ice, and they are quite visible. In some cases, useful information is extracted from ridge only imagery, but it is neither reliable, nor easy to extract without considerable expertise.

SLAR Simulations

Before the simulations started, it was assumed that the fall-off in reflectivity with angle would degrade the utility of the SLAR imagery before the loss of along track resolution, for some antenna lengths, at some altitudes. The question was to establish the altitude, and antenna length compromise which was most appropriate for the helicopter application. Since both the altitude and the antenna length have distinct practical limits, only a subset of possible parameters was examined. Examples of SLAR imagery, simulated from the SAR data collected at 9000 m altitude are shown in the report These show that at an altitude of 1500 m the limitations of azimuth resolution and the fall-off in reflectivity are similar for the 3 metre antenna image, but the azimuth smear is the limiting element for the two shorter antennas. Thus it can be concluded that at this altitude the SLAR, with a three metre antenna, would have a performance very similar to the SAR.

For an altitude of 300 m, the reflectivity fall-off clearly dominated, and even for an antenna length of 1 metre, the SLAR imagery was not seriously degraded in utility over the SAR data. For an altitude of 3000 metres, the azimuth smearing was always apparent. At an altitude of 1000 metres, both the 1 and 2 metre antennas showed azimuth smearing dominated before the loss of reflectivity. With a 3 metre antenna the two effects are both present, and a usable swath width of 10-15 km can be obtained. For a helicopter that will not likely be more than 100 km from its ship, this is not a serious limitation.

PPI Simulations

For the PPI radar at an altitude of 3000 m, it was observed that the azimuthal smearing always inhibited the image utility, unless an impractical 2 m antenna was used. At 1000 m altitude, however the 1 m antenna produced a usable range of 5-10 km, over a full 360°. This area coverage is essentially double the area coverage of a single-sided SLAR. Further, a PPI type radar covers the gap under the aircraft by looking fore and aft.

PPI style radars can be used on the helicopter for ice reconnaissance, and for a number of other tasks such as navigation and search and rescue. Since it was beyond the scope of the current study to address all these operational considerations, it is left to the CCG to consider which radar best suits their needs.

Conclusions

In the course of this study we have examined the relative image quality of helicopter borne SAR, SLAR, and PPI radars. It has been shown that the SAR, while it demonstrates very real increases in image quality at longer ranges, does so only for higher altitudes. For helicopters that are restricted in altitude, and for the relatively narrow swath widths associated with close range tactical reconnaissance, this is not a significant advantage. It is therefore concluded that either a SLAR or PPI radar would be adequate for this task. Further, given that SAR systems are more complex, heavier and much more costly that the other two types of radars, we would recommend against them, unless other criteria, not considered in this study, are brought to bear.

Of the two alternatives, SLAR and PPI, it is not currently possible to definitively declare one superior to the other, as the operational scenario against which they are to be judged is not sufficiently well defined. With SLAR, the continuous strip imagery is very compatible with the current STAR-VUE operation, which receives the SAR from the CIRS and the SLAR from the Dash-7 aircraft. However, the PPI radar is compatible with the standard PPI of the ships radar, and could easily be made to fit into the display system of STAR-VUE.

The simplest of the two radars to install, by a fair factor, is the PPI radar, as it uses a shorter antenna, and has much less of a requirement for the flight path of the helicopter to be stabilized. Further, it would be possible to use the PPI radar as a source of navigation data for the helicopter. It is therefore recommended that a radar of this type be placed aboard a CCG icebreaker helicopter, and that experiments be conducted to determine the exact requirements for such a system. It is probable that operational details of the system, as used by the CCG, will dominate the consideration of the utility, so that no amount of theoretical study will be able to address the question of what is required of such a system. The report outlines an experimental program that will identify the key issues for CCG in defining a helicopter-based radar for ice reconnaissance.

SOMMAIRE

L'hélicoptère à bord des brise-glace de la Garde côtière canadienne sert souvent aux opérations de reconnaissance des glaces. Afin d'améliorer tant en quantité qu'en qualité l'information qu'il transmet, il a été proposé de le doter de capteurs adéquats ainsi que de systèmes de télémétrie. Deux études d'optimisation ont été lancées. La première, menée par Ramseier, a trouvé que le radar imageur hyperfréquences à circuits actifs ou passifs serait le capteur optimal. La deuxième s'intéresse actuellement à déterminer lequel des radars à circuits actifs serait le plus apte à cet usage.

Trois radars différents ont été comparés: à ouverture synthétique (ROS), à visée latérale (RVL) et à écran panoramique (PPI). Pour les besoins de cette étude comparative, les chercheurs se sont servis des signaux du radar à ouverture synthétique et à haute résolution à bord du Star-1 de Intera volant à une altitude de 9000 m, qu'ils ont traités de manière à émuler l'imagerie que donnerait un autre radar à partir d'une altitude beaucoup plus faible. À cette fin, la réflectivité des glaces a dû être modélisée à partir de données connues et d'autres obtenues à l'aide du Star-1 à 1500 m d'altitude cette fois. Les altitudes auxquelles les images de synthèse devaient correspondre ont été de 300, 1000 et 3000 m, représentant les limites d'altitude inférieure et supérieure ainsi que l'altitude de fonctionnement probable d'un radar héliporté.

Les simulations effectuées ne constituent que des approximations et, faute d'une matrice de classification de la réflectivité des glaces de meilleure qualité, on peut s'attendre à des erreurs dans la représentation de certaines caractéristiques glacielles. Mais il reste que le produit final s'avère satisfaisant et que les images de synthèse ainsi produites représentent bien les images que l'on obtiendrait aux basses altitudes. En recalant les images de synthèse sur celles d'un ROS à 1500 m, et sur l'imagerie produite par un radar de bord (sans correspondance des lieux), on obtient des simulations assez fidèles. Ce procédé s'offre aussi comme un moyen adéquat pour effectuer des essais comparatifs préliminaires sans obliger à des opérations aériennes nombreuses.

Simulations du ROS

À partir de ces données, il est possible de réfléchir sur l'utilité potentielle d'un ROS héliporté. Étant donné que la réflectivité des glaces est si fortement tributaire de l'angle, les extrémités éloignées des images fournies par un ROS du type STAR-1 à 1000 m d'altitude ou moins contiendront peu d'information utile, exception faite des crêtes. Comme ces dernières ont leur propre angle d'inclinaison, l'angle d'incidence entre la glace et le signal radar sera moindre que dans le cas d'une glace uniforme, et les crêtes ne ressortiront que davantage. Dans certains cas, on peut arriver à extraire une information utile des images où seules les crêtes apparaissent, mais elle ne sera ni fiable, ni facile à extraire sans une excellente compétence technique.

Simulation du RVL

Avant la présente recherche, on croyait que l'effet qui influait le plus sur la lisibilité des images reçues était celui de la perte de réflectivité des glaces en fonction de l'angle d'incidence, avant même la perte de résolution dans le sens de la trajectoire, pour certaines longueurs d'antenne et à certaines altitudes. Il restait donc à trouver les compromis à faire dans le choix des altitudes et des longueurs d'antennes pour optimiser les opérations de reconnaissance par hélicoptères. Étant donné que la possibilité de jouer tant sur l'altitude que sur la longueur d'antenne est limitée, seule une faible partie des paramètres envisageables a pu être examinée. Le rapport donne des exemples d'imagerie RVL synthétisée à partir de l'imagerie ROS à 9000 m d'altitude. On observe que, pour une

antenne de 3 m de long, à une altitude de 1500 m, la perte de résolution azimutale et la perte de réflectivité des glaces sont d'égale influence, mais que, pour les deux autres antennes plus courtes, c'est le flou azimutal qui prédomine. Il est possible donc de dire que, à cette altitude, un RVL avec une antenne de 3 mètres serait à peu près l'égal d'un ROS.

À 300 m d'altitude, la perte de réflectivité prédomine nettement, et même avec l'antenne de 1 m, l'imagerie RVL reste lisible par rapport à celle du ROS. À 3000 m, le flou azimutal est toujours présent. À 1000 m, l'effet prédominant est celui du flou azimutal, suivi de la perte de réflectivité, que l'antenne ait 1 ou 2 m. Avec l'antenne de 3 m, ces deux effets sont simultanés, mais on obtient un couloir exploitable de 10 à 15 km de large. Dans le cas d'un hélicoptère qui ne s'éloignera probablement pas plus de 100 km du navire, ce handicap n'est pas grave.

Simulations du PPI

À 3000 m d'altitude, le flou azimutal nuit à la lisibilité de l'information, à moins d'utiliser l'encombrante antenne de 2 m. À 1000 m, l'antenne de 1 m a une portée utile de 5 à 10 km, et ce sur 360 degrés autour de l'aéronef. La lisibilité de l'information est ainsi rehaussée et la région balayée est pour ainsi dire doublée, par rapport à un RVL à simple visée. De plus, avec un PPI, l'espace sous l'aéronef est également couvert par le radar balayant de l'avant à l'arrière.

Les PPI héliportés conviennent donc aux opérations de reconnaissance des glaces, ainsi qu'à d'autres tâches, comme la navigation et la recherche et sauvetage. Mais l'aspect "opérationnel" n'étant pas inclus dans le mandat reçu, il appartient à la GCC de trancher la question du radar le plus approprié à ses besoins.

Conclusions

La recherche a été consacrée à une comparaison qualitative de l'information transmise par trois radars héliportés: à ouverture synthétique, à visée latérale et à écran panoramique. Il a pu être établi que les qualités supérieures de l'information produite par le ROS ne deviennent évidentes qu'à partir de distances-sol et d'altitudes élevées. Or, étant donné que les hélicoptères volent relativement bas et que les couloirs à balayer pour les fins de reconnaissance tactique rapprochées sont relativement étroits, cet avantage du ROS perd de son importance. La conclusion qui s'impose est que le radar soit à visée latérale, c'est-à-dire celui à l'écran panoramique est adéquat. Considérant la complexité, la masse et le coût du ROS, de beaucoup supérieurs à ceux des deux autres radars, nous recommandons de l'écarter, à moins que n'interviennent des critères d'évaluation autres que ceux pris en compte.

Pour ce qui est des deux autres radars envisagés, le RVL et le PPI, il n'a pas été possible de trancher en faveur de l'un ou de l'autre, étant donné que le contexte dans lequel la comparaison doit être faite n'a pas été suffisament défini. Dans le cas du RVL, la visée en continu est compatible avec l'état actuel du système STAR-VUE qui reçoit l'information ROS transmise par le Comprehensive Ice Reconnaissance System et l'information RVL par le Dash-7. Par contre, l'information transmise par un PPI est compatible avec les radars standard de bord et son intégration au système d'affichage STAR-VUE pourrait se faire aisément.

Le radar le plus simple à installer, et de loin, est le PPI qui utilise l'antenne la plus courte et pour qui une trajectoire très stable n'est pas une condition aussi impérative. Il peut également servir comme aide à la navigation. La recommandation est donc d'équiper un hélicoptère de la GCC d'un PPI et de procéder à des expérimentations qui permettront de définir les caractéristiques exactes voulues. Mais, en définitive, et quelques études qu'on fasse sur l'utilité éventuelle de ce radar, seule sera déterminante la question du mode d'exploitation et de l'usage qu'en fera la GCC. Enfin, le rapport propose un programme expérimental qui permettra à la GCC de cerner les caractéristiques essentielles d'un radar héliporté apte aux opérations de reconnaissance des glaces.

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 DATA SET USED 3

3.0 SAR SIMULATIONS 7
3.1 Procedure 7
3.2 SAR Simulation Results 10

4.0 SLAR SIMULATIONS 14

5.0 PPI SIMULATIONS 24

6.0 OBSERVATIONS ON THE SAR SIMULATIONS. 31
6.1 Observations on the SLAR Simulations 31
6.2 Observations on the PPI Simulations 36
6.3 Overall Observations on the Simulations 36

7.0 PROPOSED EXPERIMENTAL SYSTEM 37

8.0 PROPOSED SYSTEM DESCRIPTION 38

9.0 ESTIMATED WORK REQUIRED TO CONDUCT THE FIELD TESTS 42
9.1 Preliminary price proposal 43

10.0 CONCLUSIONS AND OBSERVATIONS 43

11.0 REFERENCES 44

LIST OF FIGURES

Figure 1. STAR-1 typical scene geometry 4

Figure 2. STAR-1 Data collected with the radar operated in the Fine Resolution Mode The Range resolution has remained at 6 metres, but a simulated azimuth resolution associated with a 1 metre long antenna has been applied to the data.... 5

Figure 3. STAR-1 Data collected with the radar operated in the Fine Resolution Mode. Pixel size 4.2 (A) X 6 (R) m, 4096X4096 Pixels shown, Actual Altitude 1524m. 6

Figure 4. Reflectivity vs Angle 8

Figure 5. The STAR-1 data low altitude SAR Simulation. Pixel size, 12X12m, 4096X4096 pixels shown, Simulated Altitude=300m..... 11

Figure 6. The STAR-1 data low altitude SAR Simulation. Pixel size, 12X12m, 4096X4096 pixels shown, Simulated Altitude=1000m. 12

Figure 7. The STAR-1 data low altitude SAR Simulation. Pixel size, 12X12m, 4096X4096 pixels shown, Simulated Altitude=3000m. 13

Figure 8. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12m, Antenna Length=1m, 4096X4096 pixels shown, Simulated Altitude=3000m.. 15

Figure 9. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12m, Antenna length=2m, 4096X4096 pixels shown, Simulated Altitude=3000m... 16

Figure 10. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12m, Antenna length=3m, 4096X4096 pixels shown, Simulated Altitude=3000m... 17

Figure 11. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12, Antenna length=1m, 4096X4096 pixels shown, Simulated Altitude=1000m... 18

Figure 12. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12, Antenna length=2m, 4096X4096 pixels shown, Simulated Altitude=1000m... 19

Figure 13. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12, Antenna length=3m, 4096X4096 pixels shown, Simulated Altitude=1000m... 20

Figure 14. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12m, Antenna length=1m, 4096X4096 pixels shown, Simulated Altitude=300m..... 21

Figure 15. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12m, Antenna length=2m, 4096X4096 pixels shown, Simulated Altitude=300m..... 22

Figure 16. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12m, Antenna length=3m, 4096X4096 pixels shown, Simulated Altitude=300m..... 23

Figure 17. This simulated PPI image has an assumed antenna length of 1 metre, and a near range incidence angle of 35°, Simulated Altitude=300m. 25

Figure 18. This simulated PPI image has an assumed antenna length of 2 metres, and a near range incidence angle of 35°, Simulated Altitude=300m. 26

Figure 19. This simulated PPI image has an assumed antenna length of 1 metre, and a near range incidence angle of 35°, Simulated Altitude=1000m..... 27

Figure 20. This simulated PPI image has an assumed antenna length of 2 metres, and a near range incidence angle of 35°, Simulated Altitude=1000m..... 28

Figure 21. This simulated PPI image has an assumed antenna length of 1 metre, and a near range incidence angle of 35°, Simulated Altitude=3000m..... 29

Figure 22. This simulated PPI image has an assumed antenna length of 2 metres, and a near range incidence angle of 35°, Simulated Altitude=3000m..... 30

Figure 23. SLAR imagery simulated from collected SAR data, 1500m altitude, 1 metre antenna..... 33

Figure 24. SLAR imagery simulated from collected SAR data, 1500m altitude, 2 metre antenna..... 34

Figure 25. SLAR imagery simulated from collected SAR data, 1500m altitude, 3 metre antenna..... 35

Figure 26. A Sketch of the Proposed Radar Installation on a CCG Helicopter..... 39

Figure 27. The Proposed Helicopter Radar Installation..... 40

Figure 28. Equipment proposed for this experiment..... 41

1.0 INTRODUCTION

This study reported on in this document was intended to provide a cost effective means of evaluating the various the various options available to the Canadian Coast Guard to provide radar ice reconnaissance capability from their ship-borne helicopter fleet. The study made use of fine resolution data from a commercial Remote Sensing system, and mathematical simulations to provide the CCG with data representative of a range of different radar systems that could, in theory, be placed aboard a helicopter.

Fine resolution airborne Synthetic Aperture Radar (SAR) ice reconnaissance systems have become the accepted standard for both operational and research programs. The all weather performance of radar, combined with the ability of SAR to match the resolution, swath width and data rate to the needs and means of the user, has made SAR the ideal ice reconnaissance sensor. SAR systems, such as the dual-sided Comprehensive Ice Reconnaissance System (CIRS) operated by INTERA provide operational, wide area coverage, from high altitude aircraft. These data are useful for both long term ice climatology and strategic and tactical navigation support purposes. However, they have a rather short useful lifetime for close tactical support in moving ice conditions. It is therefore desirable to provide ships, navigating in ice infested waters, with real time information, similar to that available from SAR, for close tactical support.

In the past, close tactical information has been available to a ship's crew from the ship's radar, and, if available, from the ship's helicopter based on visual reports from the pilot or ice observer. The ship's radar, at heights above ice typically less than 30 metres, is not able to image the ice beyond ranges of a few km. Further, the range and angular resolutions are typically not adequate for a high quality image of the ice. Visual reporting from a helicopter, while very useful, is limited to conditions of good visibility, and provides no permanent record that can be used for interactive decision making on board the ship. The solution that would seem to present itself to those operators that carry helicopters is to equip them with imaging radars that return the images to the ship, either as a record, or on a telemetry link of the type used in the CIRS program. Naturally, since SAR provides the best data from a fixed wing, high flying aircraft, the proposal has been made to equip some Canadian Coast Guard (CCG) helicopters with SAR systems.

A helicopter is not an ideal platform for an imaging radar, as it flies too low, and often flies with highly variable ground speed and direction. Since SAR systems require very controlled, linear flight lines, they require extensive motion compensation to fly on helicopters. SARs are also heavy and expensive, even in the simpler versions intended for fixed wing aircraft. These problems will in time be overcome as lighter, more powerful computer equipment becomes available. It is therefore worth analyzing very carefully if a SAR is truly the right sensor to place on a helicopter.

A more serious problem, is the rather low altitudes at which helicopters typically fly. This means, that for any significant swath width, the angle of incidence of the radar energy at the ice surface can be very shallow. Although the ice may not be hidden behind the curvature of the earth, as in the case of the shipborne radar, the ice is viewed, for all but the part of the image closest to the flight path, at very shallow angles.

Provided the illumination angle of the radar is kept in the moderate angles (10 to 70°), the reflectivity of sea ice is relatively stable, and imagery is easily interpreted. At very steep or very shallow illumination angles, the reflectivity becomes a strong function of the angle. Further, this variability of reflectivity is very ice type dependant . At shallow angles, ice that is not deformed, and therefore being viewed at what is effectively a grazing angle, becomes a nearly specular reflector, and the illuminating energy is reflected away, and not returned to the radar. As a result, undeformed ice becomes invisible to radar at very shallow angles. The angle at which ice starts to become a very poor reflector is a function of both the salinity and the details of the surface morphology of the ice. The significance of this for helicopter reconnaissance is that unless the craft is flown at very high altitudes, the energy returned from the far edge of the swath will come almost exclusively from deformed ice. Thus either the helicopter must be flown at very high altitudes or the swath widths must be kept to very narrow ranges to generate useful, and reliably interpreted ice imagery.

Since the purpose of the helicopter radar is to provide close range, tactical information, keeping the swath width restricted is not a severe limit. If one accepts that the radar will be restricted to low altitude by its operating capabilities, and the swath width will be kept restricted by the physics of the radar-ice interaction, then the possibility of substituting a real aperture radar, commonly called a Side Looking Airborne Radar (SLAR) or a Search type radar for the SAR presents itself. These radars are typically simpler and cheaper than SAR systems, and so their use on a fleet of helicopters is practical.

The prime advantage of the SAR over the SLAR or Search radar is the ability to maintain constant azimuthal, or along track resolution over wide swaths. This means that the resolution of the SAR is not a function of range, and that the resolution will be the same at the near and far edge of the swath. If there is a restricted swath due to the physics of the radar-ice interaction, this capability could well be of little advantage. It is therefore possible that the far range degradation seen in real aperture radars may not be serious for narrow swath radars used for helicopter reconnaissance in a close tactical support role. This means it may be practical to have a 'SAR' level of ice information with the weight and expense limits normally associated with simple Real Aperture Radars. This means a savings in capital cost of at least a factor of 20 and a weight reduction of a factor of 5 or more. Further, if the radar chosen does not require extensive motion compensation, there will be a commensurate saving in the cost of the helicopter navigation system. These savings are rather substantial, and deserve study.

To investigate the compromises involved in choosing a helicopter radar, INTERA undertook to provide the Canadian Coast Guard with a series of simulated images that would have the 'look and feel' of the imagery that would be expected from a helicopter borne radar, flown at low altitudes (1000 to 10000 feet ASL). The basis for the simulation was SAR imagery that was filtered and processed to represent data collected from radars flown at lower altitude.

Three types of low altitude radars were simulated; a SAR, a SLAR, and a Search or PPI type radar. The SAR simulation consisted of modifications to the brightness values of the data to simulate the lower altitude, and therefore the more shallow illumination that would be obtained from a helicopter. The algorithm for this transform was evolved empirically, using data collected from a low altitude SAR pass as a reference. The SLAR simulation was applied over the SAR simulation and consisted of a variable low pass spatial filter used to simulate the degraded far range resolution associated with a real aperture system. The PPI simulation combined the radiometric and geometric simulations of the SAR and SLAR simulations, but with the antenna assumed to be rotating at a point above the image centre.

2.0 DATA SET USED

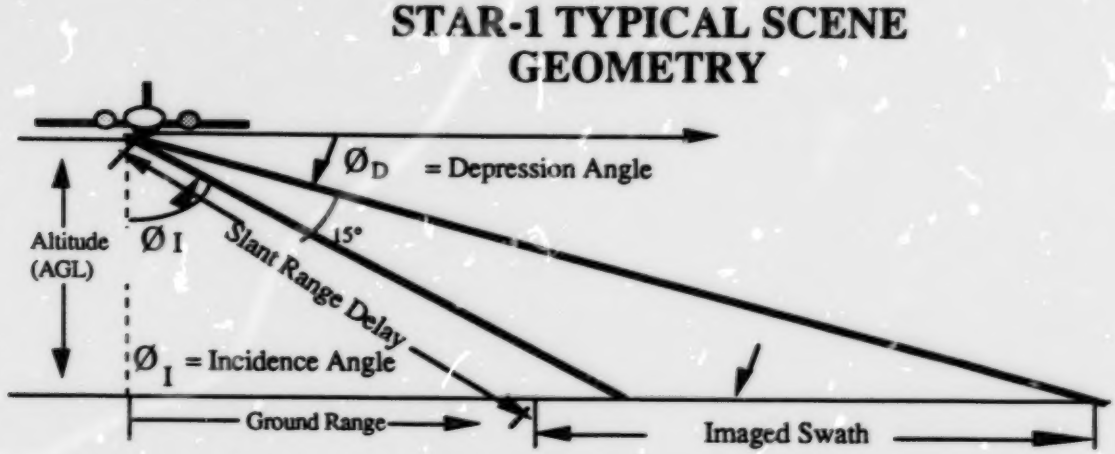
In November 1988, the INTERA STAR-1 system was mapping ice in Lancaster Sound in support of programs for the Canarctic Shipping Company Ltd. Data from this mission were selected for further study. These data contained a wide mix of ice types, including newly forming ice, thicker first year ice, and old ice that appeared to consist of both second year and multi-year ice. The data were collected at 9100 m (30,000 feet) altitude, with the radar in the wide swath mode. A schematic of the scene geometry is shown in Figure 1. Also shown are calculations on the scene geometry that correspond to the altitudes simulated in the study. (The measurements, in cm. refer to the size on the original 1:250,000 imagery used in the study. The images in this, the final draft of the report, have been reduced in size somewhat to fit in the report format.)

In this mode the radar has an effective swath width of 46 km, with a range pixel size of approximately 12 metres. The incidence angle varied from 23.3° at the near edge of the swath to 7.8° at the far edge of the swath. The azimuth (along track) spacing of the data lines was reduced in processing from 4.2 to 12 metres to both give 'near square' pixels, and to reduce the effects of coherent fading or speckle. A scene of 4096 lines by 4096 pixels was selected from the data to be studied and is shown in Figure 2.

Two days later, a second pass was made over the same area, using the same flight line, at an altitude of approximately 1500 metres (5000 feet) with the radar operated in the fine resolution mode. This provided a calibration altitude image set to develop the empirical transfer function. In this mode, the range pixel size is 6 metres, giving an effective swath width of 23 km. The incidence angle varied from 7° at the near edge of the swath to 2.4° at the far edge of the swath. The data were studied with the line spacing of 4.2 metres. A scene from the same area as that shown in Figure 2 was selected for detailed comparison. It is shown in Figure 3. Note that the finer resolution provides greater textural discrimination, and the data are presented at the same scale, and as a result the image is seen to be much smaller. The purpose of these data is not to demonstrate resolution effects, but to demonstrate depression angle effects.

A striking difference between the two scenes is seen in the small old ice floes in the centre right of the image. At steeper angles typical of Figure 2, these floes are seen to be 'old' ice, and show up as having a bright tone. In Figure 3 they are seen at a more shallow angle, and are indistinguishable from first year ice. This demonstrates the dramatic contrast changes that happen at shallow angles. This effect leads to the conclusion that the data at shallow angles are not reliable.

Figure 1 STAR-1 Typical Geometry



Ground range is calculated from the flight path of the aircraft; Slant range is calculated from the aircraft; Depression angle is calculated from the horizontal; and Incidence angle is calculated from the (assumed) flat earth.

Wide Swath Data					Wide Swath Data					Wide Swath Data				
cm	Alt	Delay	GR	øi	cm	Alt	Delay	GR	øi	cm	Alt	Delay	GR	øi
0	9100	23000	21123	23.3	0	1000	1732	1414	35.3	0	300	520	425	35.2
1	9100	23000	25823	19.4	1	1000	1732	6114	9.3	1	300	520	5125	3.4
2	9100	23000	30523	16.6	2	1000	1732	10814	503	2	300	520	9825	1.7
3	9100	23000	35223	14.5	3	1000	1732	15514	3.7	3	300	520	14525	1.2
4	9100	23000	39923	12.8	4	1000	1732	20214	2.8	4	300	520	19225	0.9
5	9100	23000	44623	11.5	5	1000	1732	24914	2.3	5	300	520	23925	0.7
6	9100	23000	49323	10.5	6	1000	1732	29614	1.9	6	300	520	28625	0.6
7	9100	23000	54023	9.6	7	1000	1732	34314	1.7	7	300	520	33325	0.5
8	9100	23000	58723	8.8	8	1000	1732	39014	1.5	8	300	520	38025	0.5
9	9100	23000	63423	802	9	1000	1732	43714	1.3	9	300	520	42725	0.4
9.7	9100	23000	66713	7.8	9.7	1000	1732	47004	1.2	9.7	300	520	46015	0.4
Wide Swath Data					Wide Swath Data					Wide Swath Data				
cm	Alt	Delay	GR	øi	cm	Alt	Delay	GR	øi	cm	Alt	Delay	GR	øi
0	1500	2500	2124	35.2	0	3000	5200	4247	35.2	0	524	13000	12910	6.7
1	1500	2600	6824	12.4	1	3000	5200	8947	18.5	1	524	13000	15260	5.7
2	1500	2600	11524	7.4	2	3000	5200	13647	12.4	2	524	13000	17610	4.9
3	1500	2600	16224	5.3	3	3000	5200	18347	9.3	3	524	13000	19960	4.4
4	1500	2600	20924	4.1	4	3000	5200	23047	7.4	4	524	13000	22310	3.9
5	1500	2600	25624	3.4	5	3000	5200	27747	6.2	5	524	13000	24660	3.5
6	1500	2600	30324	2.8	6	3000	5200	32447	5.3	6	524	13000	27010	3.2
7	1500	2600	35024	2.5	7	3000	5200	37147	4.6	7	524	13000	29360	3.0
8	1500	2600	39724	2.2	8	3000	5200	41847	4.1	8	524	13000	31710	2.8
9	1500	2600	44424	1.9	9	3000	5200	46547	3.7	9	524	13000	34060	2.6
9.7	1500	2600	47714	1.8	9.7	3000	5200	49837	3.4	9.7	524	13000	35705	2.4

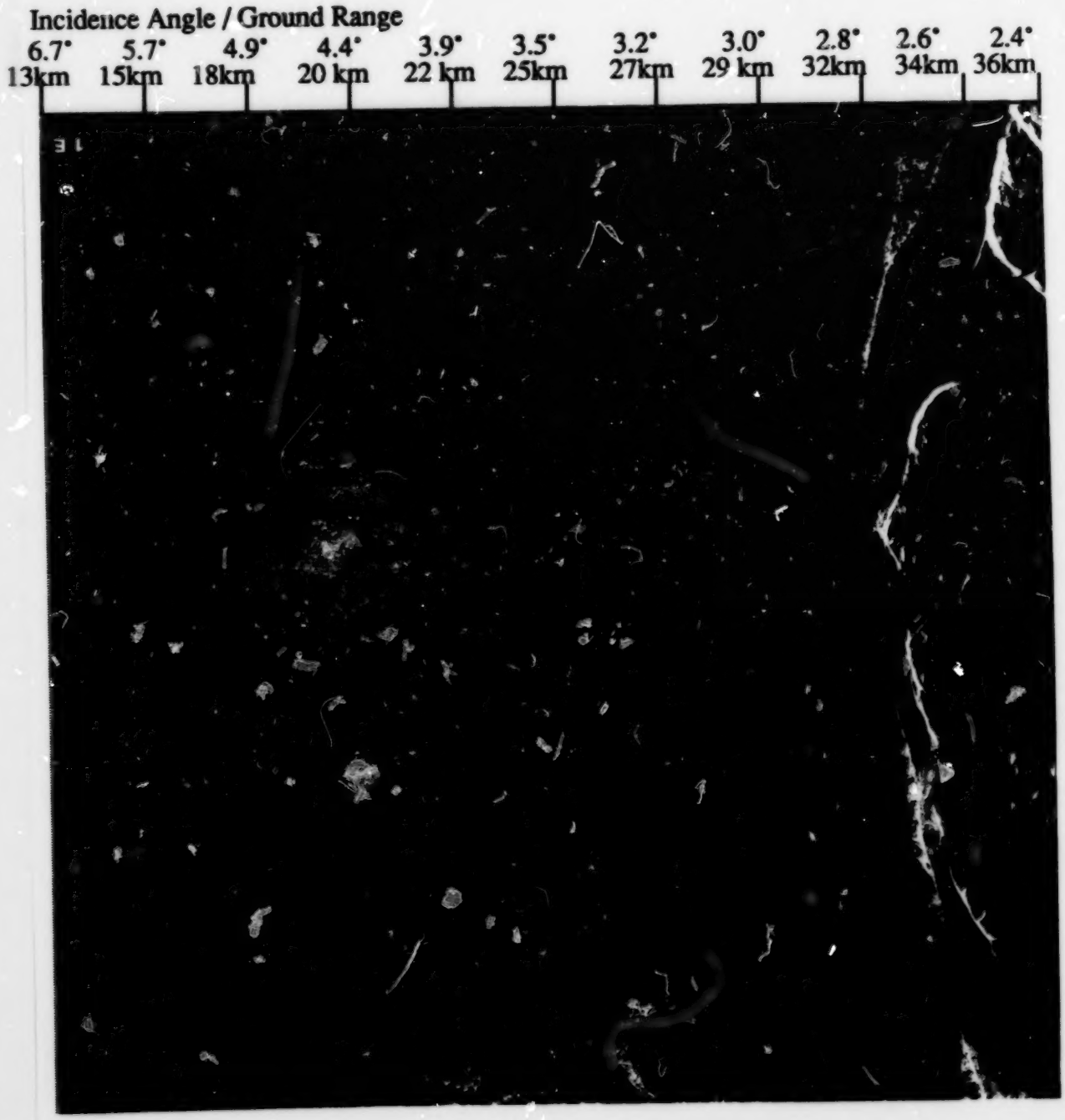


Figure 2. STAR-1 Data collected with the radar operated in the Fine Resolution Mode. The Range resolution has remained at 6 metres, but a simulated azimuth resolution associated with a 1 metre long antenna has been applied to the data.

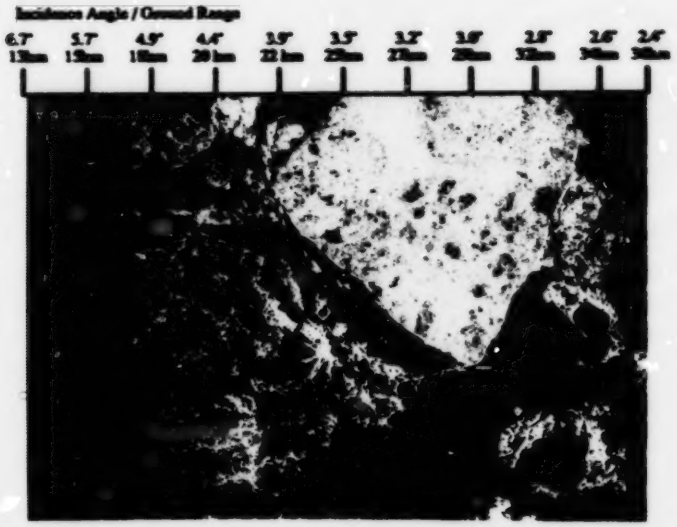


Figure 3. STAR-1 Data collected with the radar operated in the Fine Resolution Mode. Pixel Size 4.2 (A) X 6 (R) m, 4096X4096 Pixels shown, Actual Altitude 1524m.

3.0 SAR SIMULATIONS

3.1 Procedure

To simulate an airborne SAR flying at a lower altitude, it is necessary to have a model of the reflectivity of sea ice as a function of both ice type and angle. The radar reflectivity of sea ice is a strong function of the angle of illumination. This is particularly true at very shallow angles which are typical of marine radars (incidence angles between 0 and 3°). While considerable data are available on the reflectivity of sea ice at angles typical of satellite or airborne radars (Ulaby and Dobson, 1989, Long 1983), there have been very few experiments that have provided quantitative reflectivity data at these shallow angles. Some unpublished data were available to INTERA from a SLAR operated by NASA from their Lewis research facility, based on experiments conducted in the late 70's. These were combined with other data from steeper angles to arrive at a model of Sea Ice Reflectivity which was used to design STAR-1. These data are presented in Figure 4 for reference, however, they should be treated with caution, as they have not been verified. It is very difficult to make measurements at very shallow angles, as any real beam tends to cover a very large number of ice types, and synthetic beams (SAR) are very hard to calibrate. As a result few high quality data are available to verify this set of curves, and they are used as the 'best available'.

To apply an ice type specific reflectivity model to the data requires a means of classifying the data into ice types that exhibit different angular reflectivitiy characteristics. There have been several attempts to classify ice based on a single frequency and polarization, namely X-band, HH. These attempts have been largely unsuccessful, however because the ice types have significant overlap in their reflectivity. The data set shown in Figure 2 and 3 was examined to assess the separability of ice by category, based solely on X-HH reflectivity. It was noted that there was significant overlap in reflectivity between old ice and second year Ice as well as with younger ice forms such as ridges and rubble and even with new leads covered with frost flowers. As it was beyond the scope of this study to examine tonal/textural and other more complex classifiers, a very simple tonal or 'density slice' classifier was used. It is argued that the results of the simulation, while reduced in scientific validity by this simplification, will still serve their intended purpose of showing the type of imagery that such radar systems would generate.

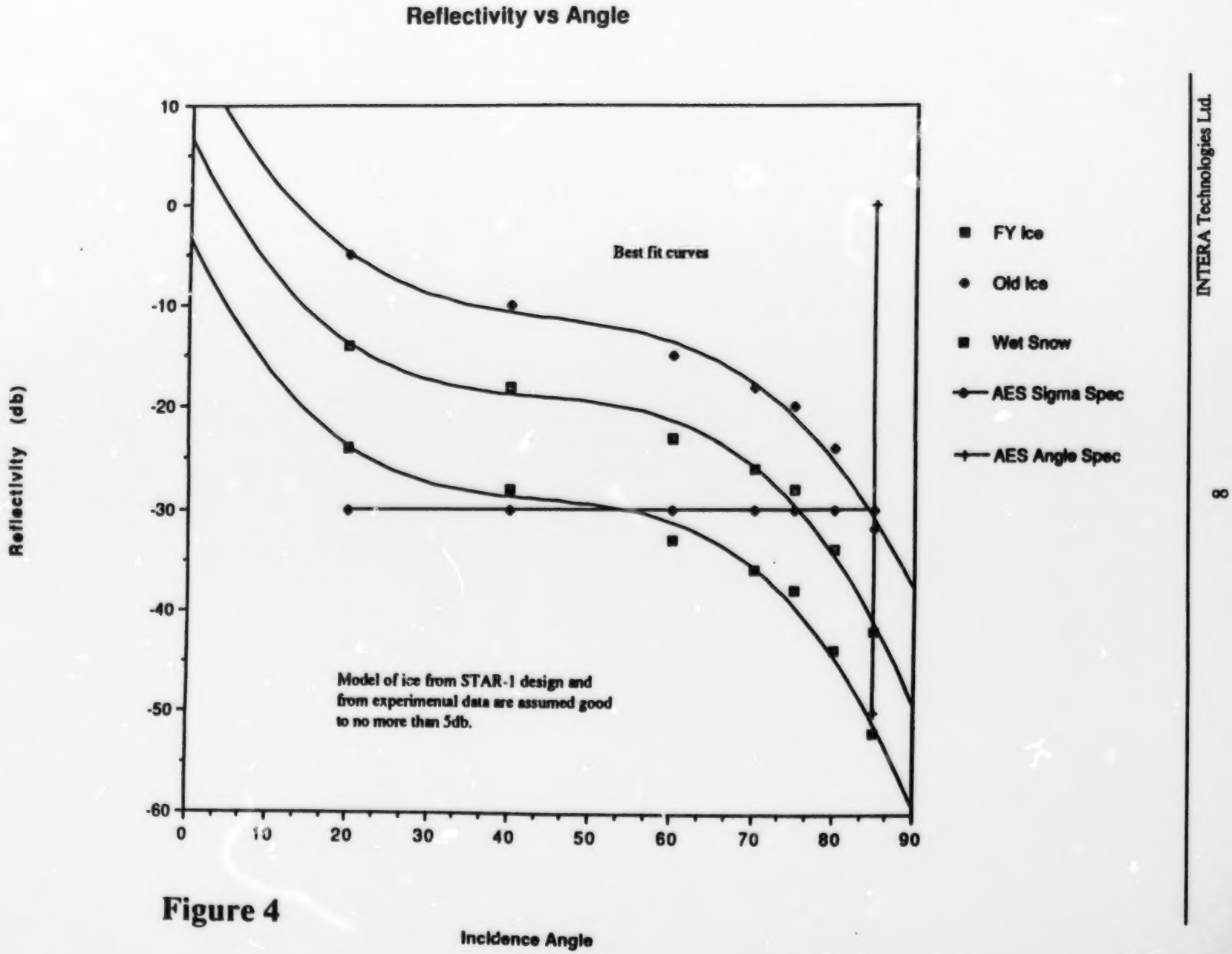

Reflectivity vs Angle
Reflectivity (db)
10
0
-10
-20
-30
-40
-50
-60
0
10
20
30
40
50
60
70
80
90
Incidence Angle
Best fit curves
Model of ice from STAR-1 design and from experimental data are assumed good to no more than 5db.
FY Ice
Old Ice
Wet Snow
AES Sigma Spec
AES Angle Spec
INTERA Technologies Ltd.
8

Figure 4

The reflectivity model used was to classify the ice was based on a simple density cut. For example, all ice with reflectivity between 0 and 40 (on a scale of 0-255) was treated as first year ice. Then each class was treated with a separate roll-off curve as a function of the incidence angle Ø. The curve took the form:

If $Ø < \text{Cutoff Angle}$ $\quad X_{out} = \text{Gain} * X_{in}$

If $Ø \geq \text{Cutoff Angle}$ $\quad X_{out} = \text{Gain} * X_{in} * (255 ** (-1*D*S))$

where $S = (Ø - Ø_{co})/(90° - Ø_{co})$
i.e. linear 0 to 1 for $90° \leq Ø \leq Ø_{co}$

where for each intensity range, the Cutoff Angle ($Ø_{co}$), Gain (G), and Decay Coefficient (D), were specified. The values were chosen by trial and error, based upon experience with SLAR, and Marine Radars, and by a detailed comparison of the data sets collected at altitudes of 1500 metres and 9100 metres.

The rational behind the cutoff angle portion of this algorithm is as follows: It has been noted that the reflectivity of ice begins to fall off rapidly at some angle between 0 and 10° incidence , and that this exact angle is a function of the ice type (see Figure 4). For first year ice and young ice forms such as leads covered in frost flowers, this angle tends to be between 5 and 7°. For older ice it is more shallow, occurring at 3 to 5°. For ridges and other 'deformed' ice types, the falloff occurs nearer to 0°. Assuming for the moment that simple reflectivity could distinguish between these categories, a cutoff angle is assigned to each intensity range. The simulation consists of calculating the applicable angle, and applying the calculated coefficient.

The Decay coefficient determines the speed of falloff of reflectivity after the cutoff angle has been reached. Again, this is based on observations of Marine radar data, more than on published statistics, and was arrived at in an empirical fashion. The values used were arrived at by comparing filtered versions of Figure 2 with data from the low altitude pass shown in Figure 4.

The decision to apply Gain to certain categories is based again on observations of marine radar data. Features such as ridges, large rubble fields and icebergs often exhibit a marked increase in reflectivity at very shallow angles, relative to the average reflectivity of the scene. Again, the value of the gain used was calibrated against the data collected at 1500 and 9100 m altitude.

The values used in the simulation are relative to the data in Figure 2. The STAR-1 radar is not calibrated to an absolute radiometric standard, although it has been shown to be possible to do relative calibration. Therefore the values arrived at in this simulation have little external relevance but the coefficients used have been tabulated below for reference.

Reflectivity Range	Cutoff Angle	Gain	Decay
0-4085.0°	1.0	1.0	
41-6086.5°	1.3	1.1	
61-9087.0°	1.5	1.1	
91-255	88.5°	1.5 1.2	

3.2 SAR Simulation Results

The scene selected and shown in Figure 2 was processed using the algorithm shown in the previous section. Altitudes of 300,1000, and 3000 metres were selected for simulation. The 300 and 3000 metre altitudes were selected as being the limits of operational flight altitudes. The 1000 metre altitude was selected as it represents the altitude most commonly flown during helicopter ice reconnaissance flights. The results of these simulations are shown in Figures 5 (300 metres), Figure 6 (1000 metres), and Figure 7 (3000 metres).

From these images it is clear that the utility of the radar imagery falls off with the incidence angle. The 300 m (Figure 5) altitude image is of use over a 5 km swath width. The falloff with angle effectively eliminates returns from farther range. At higher altitude, the image utility extends further, as shown in Figure 6 (1000m) where the reflectivity is stable out to 15 km range. Beyond that range, only the ridges are reliably mapped. At 3000 m altitude (Figure 7), the loss of reflectivity in the younger ice forms starts at about 30 km, but the roll-off after this point is much more gentle. From this altitude it would clearly be of interest to have a SAR.

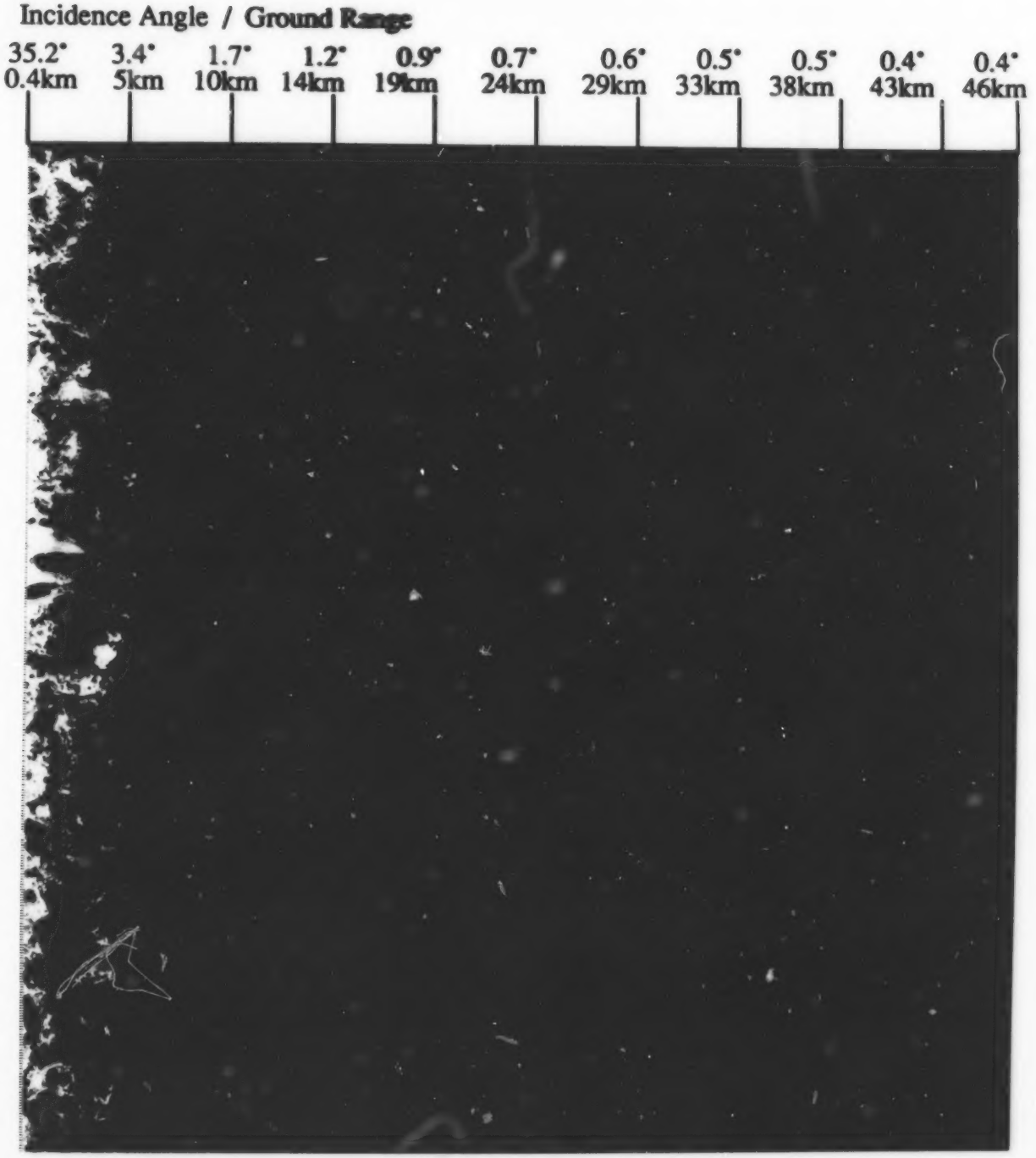


Figure 5. The STAR-1 data low altitude SAR Simulation. Pixel size, 12X12 m, 4096X4096 pixels shown, Simulated Altitude = 300 m.

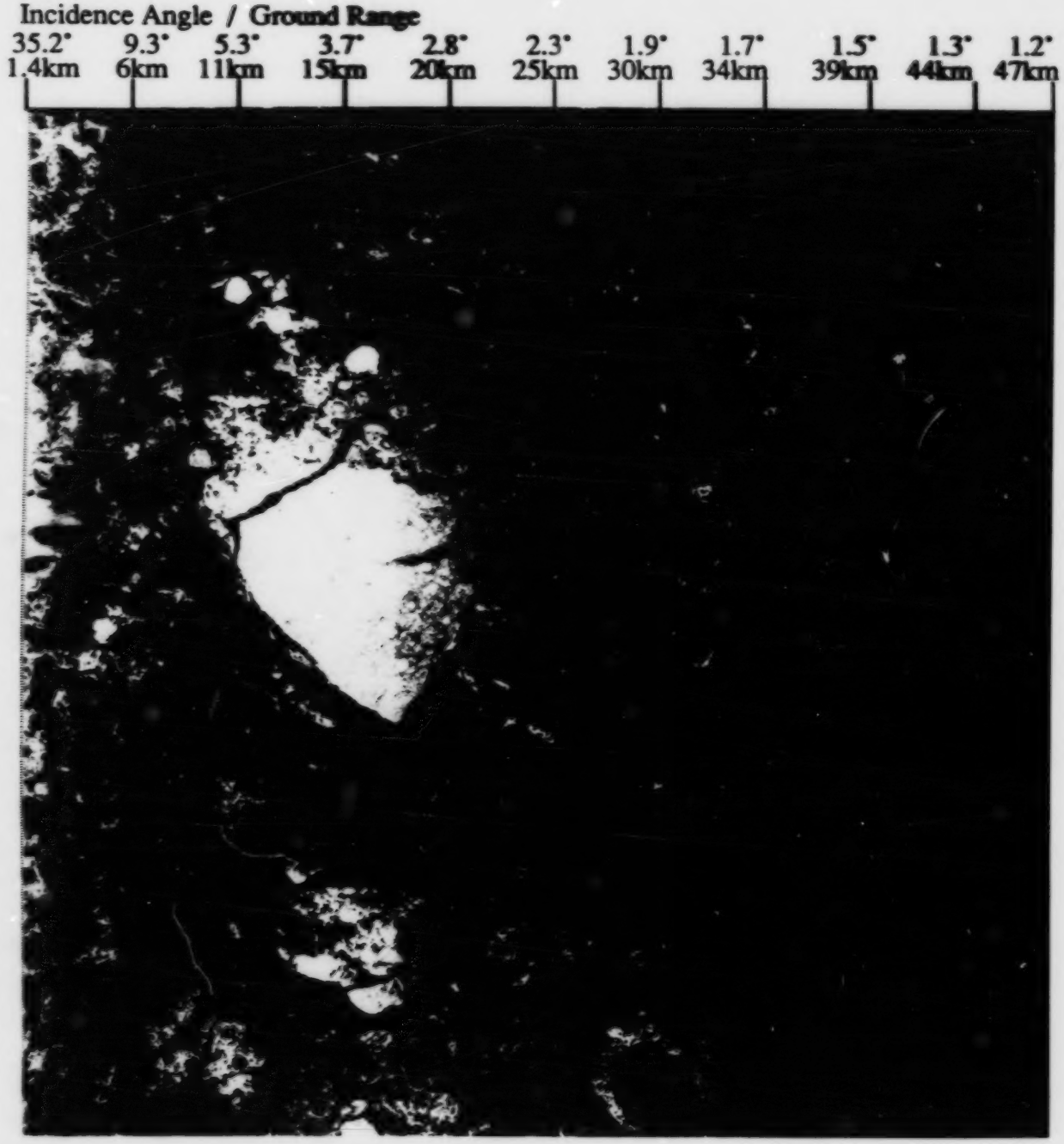


Figure 6. The STAR-1 data low altitude SAR Simulation. Pixel size, 12X12 m, 4096X4096 pixels shown, Simulated Altitude = 1000 m.

Figure 7. The STAR-1 data low altitude SAR Simulation. Pixel size, 12X12m, 4096X4096 pixels shown, Simulated Altitude = 3000 m

4.0 SLAR SIMULATIONS

The SLAR simulation is based on the same reflectivity assumptions as the SAR simulations. The difference in the along track resolution however was simulated by having a range dependent low pass filter reduce the effective resolution of the data. The beamwidth of the antenna was estimated from the length of the antenna, assuming a simple un-weighted antenna, using the formula;

$$\int = \neg / L$$

where $\neg$ = Radar Wavelength,
L= Antenna Length, and
$\int$= The effective Antenna Beamwidth (in Radians).

The length of the low pass filter used in the along track dimension was calculated based on the range and the beamwidth, using the simple formula;

$$W = (R * \int) / ®_a$$

where W is the filter width in pixels,
R is the range to the pixel being filtered, and
$®_a$ is the SAR azimuthal pixel size.

The data were then filtered with a simple box car low pass filter of this size. This resulted in a rather smeared image at far ranges, for a short antenna. For example, the beamwidth of a 1 metre antenna at X band ($\neg$=3.2 cm) is 0.032 radians (1.8°) giving a resolution of 320 metres at a range of only 10 km. With the SAR pixel of 12 metres there is a smearing of more than 26 pixels.

The images generated for the SLAR simulation are based on the same data simulated for lower altitudes for the SAR simulations, but with the low pass filter applied. That is, the altitude simulations used for the SAR are the same for the SLAR. Examples of the simulations are shown in Figures 8 through 16. Here the antenna length and altitude of simulation have been varied. Antenna lengths of 1, 2, and 3 metres have been used for the three altitudes 300, 1000, and 3000 metres. The results are very interesting and show the types of compromises that can be made.

The two extreme cases, a 1 metre antenna at 300 metres altitude, and the 3 metre antenna at 3000 metres altitude demonstrate the dramatic differences to be observed. At 300 metres altitude, it is arguable that there is little information lost with any length of SLAR antenna, as the falloff due to incidence angle dominates. At 3000 metres altitude, the azimuthal smearing dominates at all antenna lengths, although it is obvious that the imagery is still of considerable use where the angle rolloff starts (at 3-4°). Of great interest is Figure 13 which shows that a SLAR with antenna length of 3 metres, at an altitude of 1000 metres can achieve an effective swath width of approximately 15 km. This compromise represents a truly viable option for CCG. This is because, with such a SLAR, the imagery contains almost all the information that can be obtained by a SAR at the same altitude. The differences are in the cost, weight, and complexity if the system, not the utility.

Figure 8. The STAR-1 data low altitude SLAR Simulation. Range Pixel size= 12 m, Antenna Length=1 m, 4096X4096 pixels shown, Simulated Altitude = 3000 m.

Figure 9. The STAR-1 data low altitude SLAR Simulation. Range Pixel size= 12 m, Antenna Length=2 m, 4096X4096 pixels shown, Simulated Altitude = 3000 m.

Figure 10. The STAR-1 data low altitude SLAR Simulation. Range Pixel size= 12 m, Antenna Length=3 m, 4096X4096 pixels shown, Simulated Altitude = 3000 m.

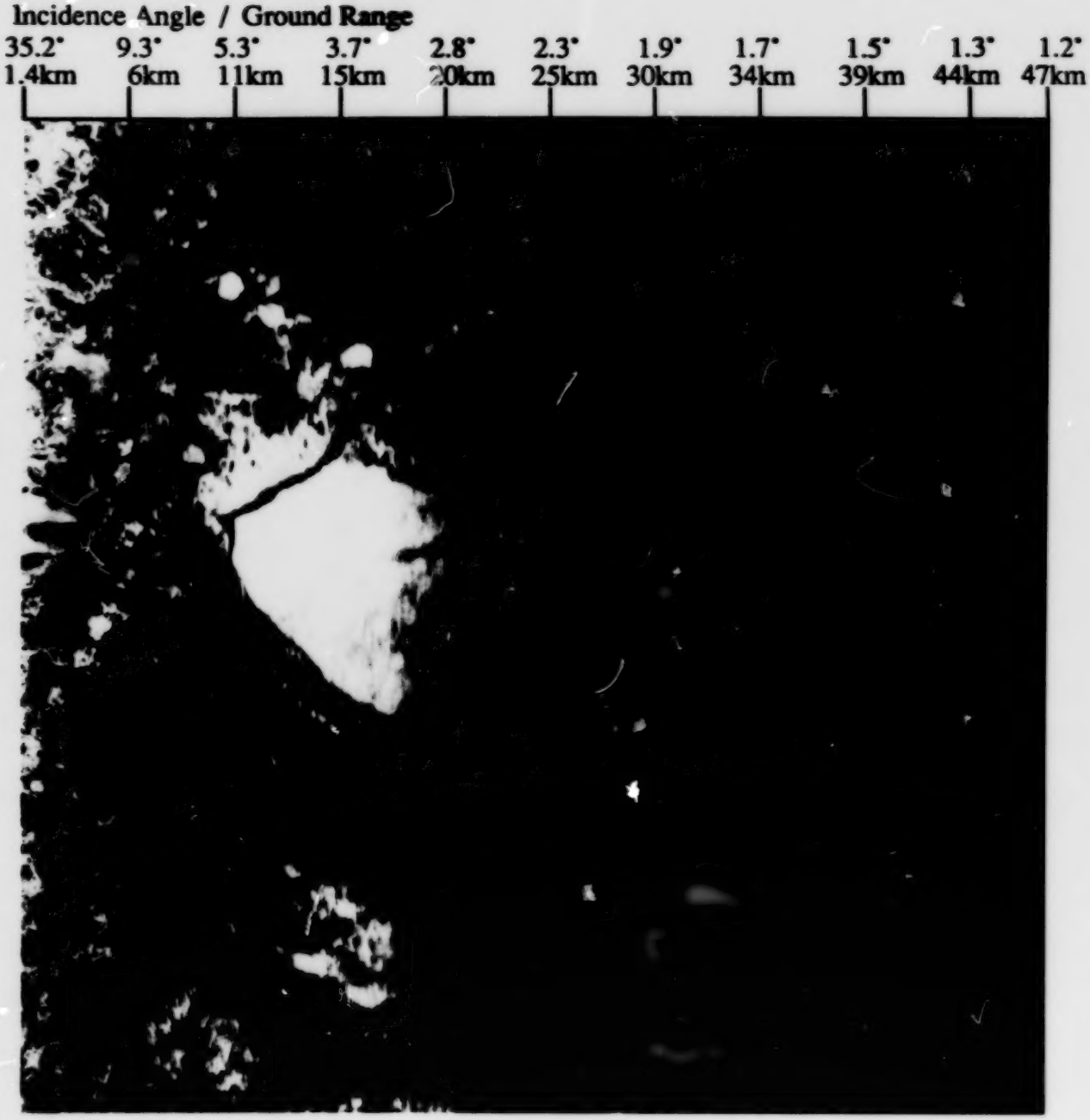


Figure 11. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12, Antenna length = 1 m, 4096X4096 pixels shown, Simulated Altitude = 1000 m.

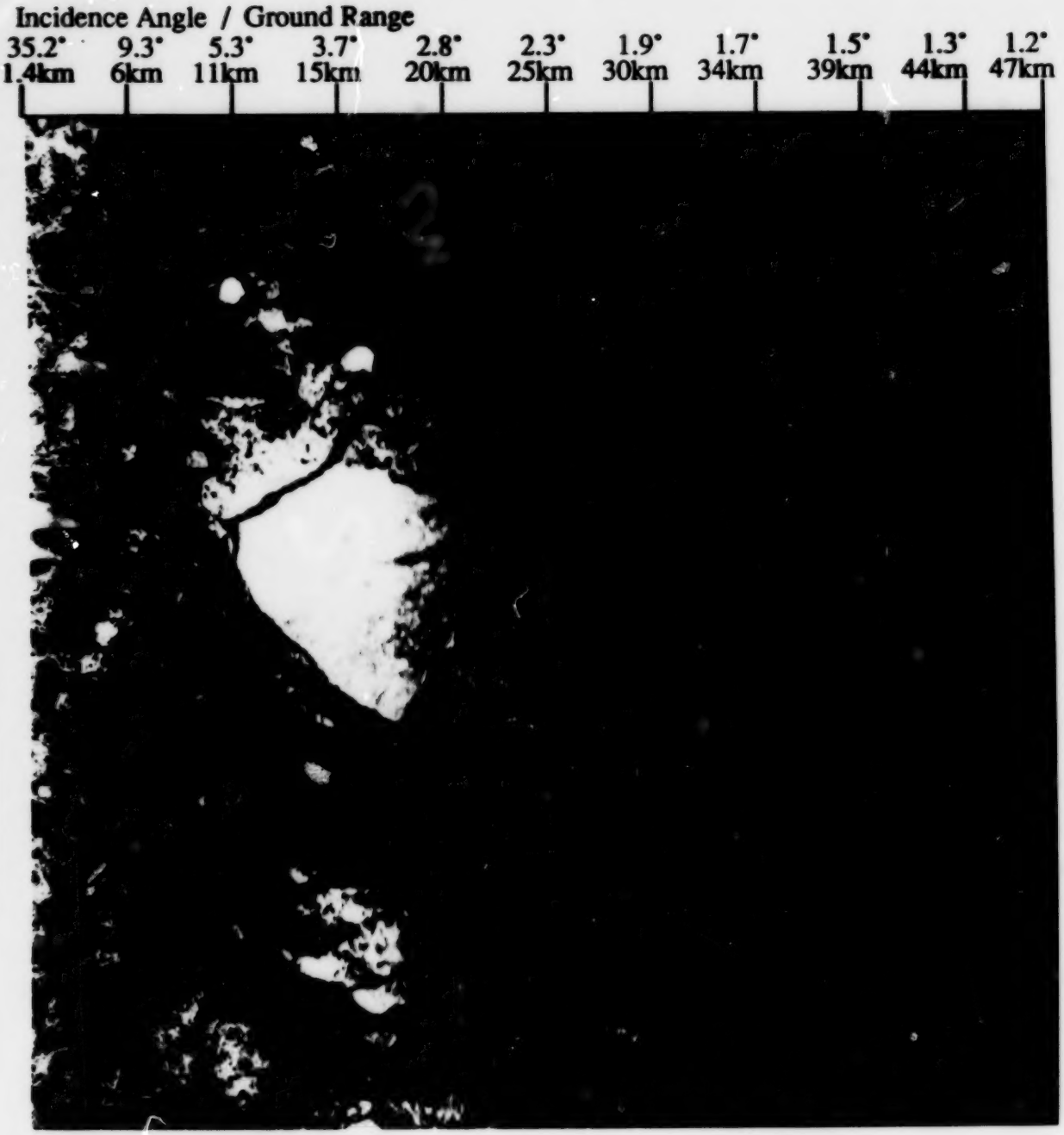


Figure 12. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12, Antenna length = 2 m, 4096X4096 pixels shown, Simulated Altitude = 1000 m.

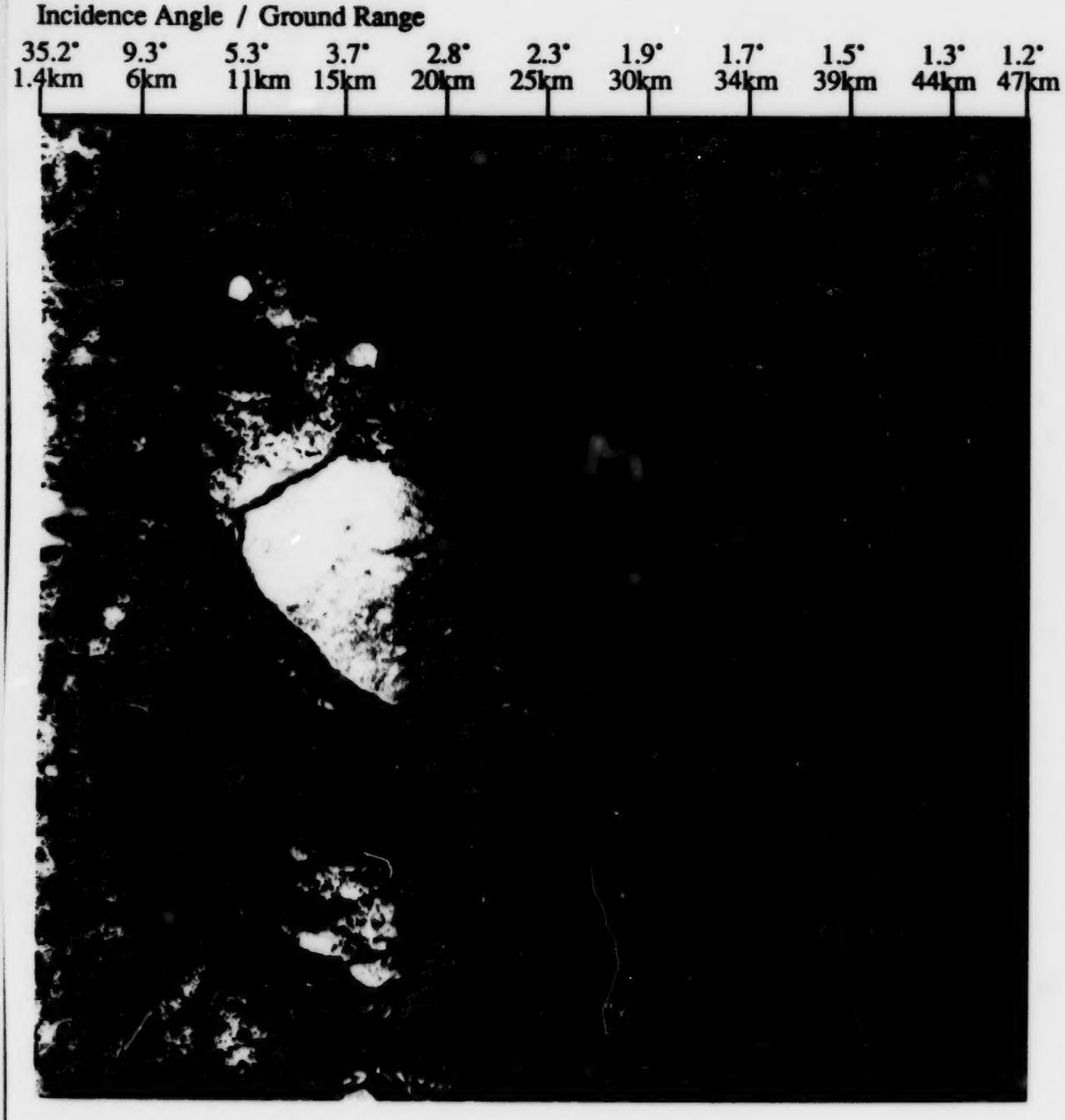


Figure 13. The STAR-1 data low altitude SLAR Simulation. Range Pixel size=12, Antenna length = 3 m, 4096X4096 pixels shown, Simulated Altitude = 1000 m.

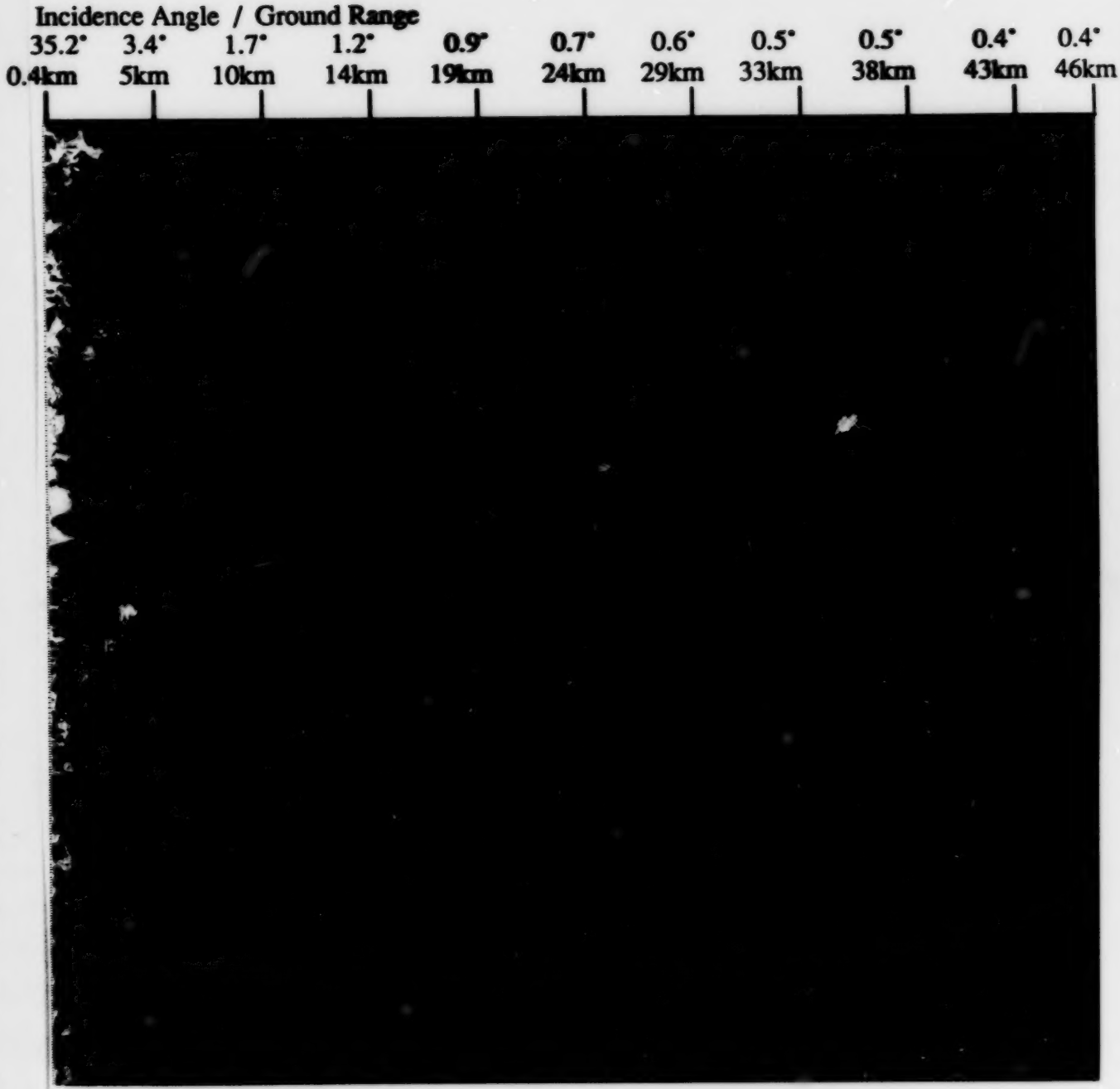


Figure 14. The STAR-1 data low altitude SLAR Simulation. Range Pixel size = 12 m, Antenna Lenght = 1 m, 4096X4096 pixels shown, Simulated Altitude = 300 m.

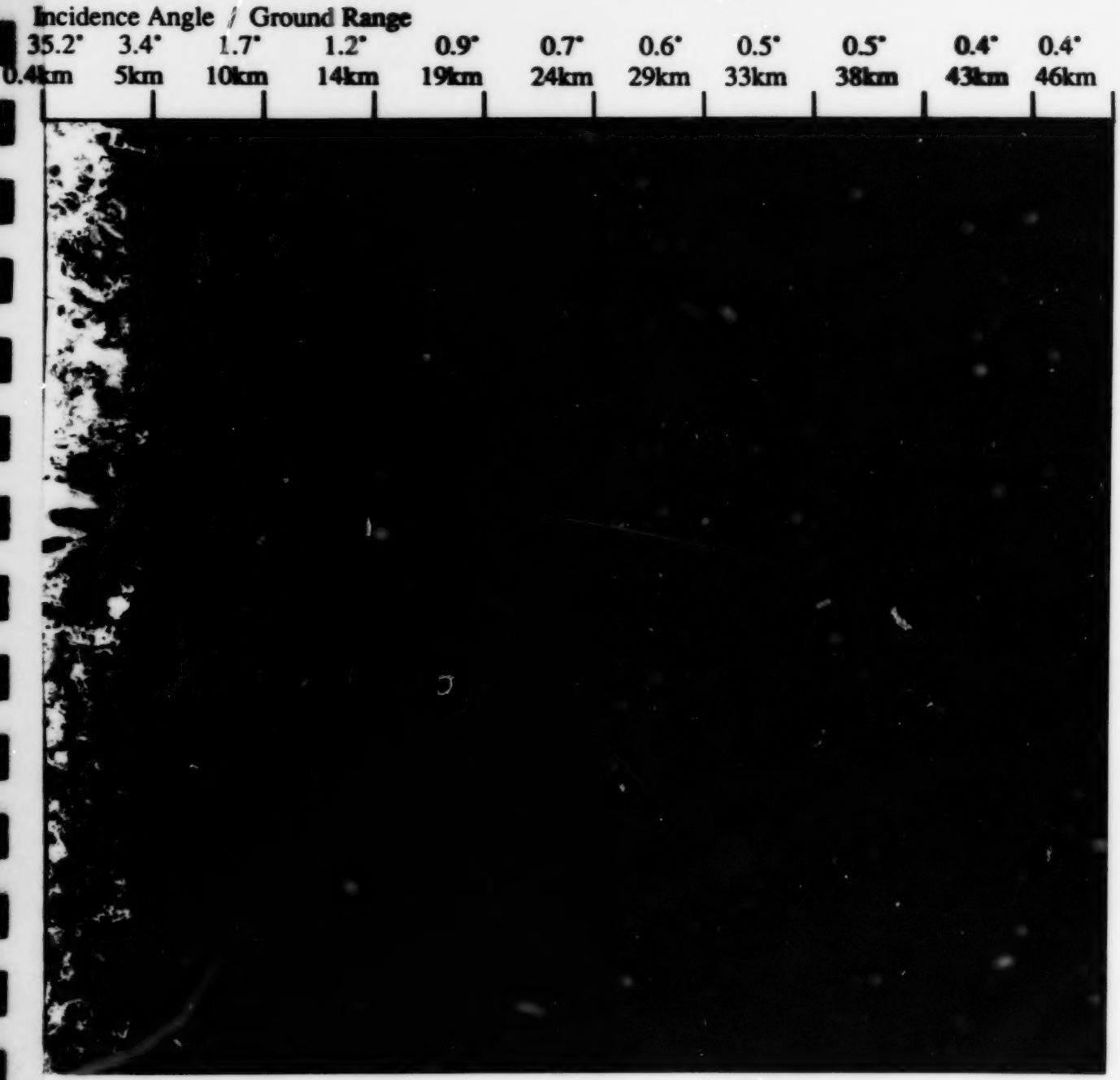


Figure 15. The STAR-1 data low altitude SLAR Simulation. Range Pixel size = 12 m, Antenna Lenght = 2 m, 4096X4096 pixels shown, Simulated Altitude = 300 m.

Figure 16. The STAR-1 data low altitude SLAR Simulation. Range Pixel size = 12 m, Antenna Lenght = 3 m, 4096X4096 pixels shown, Simulated Altitude = 300 m.

5.0 PPI SIMULATIONS

The simulation of the PPI radar imagery involved the application of the same algorithms developed for the two previous simulations, but with the scene geometry much modified. A helicopter was assumed to be flown down the centre of the 46 km wide swath of SAR data, at the 4 altitudes selected for simulation, with both a 1 and a 2 metre antenna, for a total of 8 simulated scenes. The data from the SAR were first reduced, by simple averaging to 24 X 24 metre pixels, both to make the computations more tractable, and to simulate a more realistic resolution capability for the PPI radar. However, for the most part, the imagery presented here is resolution limited at the paper print production stage, and the differences are not obvious. The PPI simulations were conducted for antenna lengths of 1 and 2 metres, and for altitudes of 300, 1000, and 3000 metres, and are shown in Figures 17 through 22.

As with the SAR simulations, the intensity of the returns was calculated on the basis of the depression angle, and the scene intensity. The incidence angle to be used was calculated from the helicopter location, which was assumed to be at a point in the centre of the original SAR swath. The higher the intensity in the source SAR data, the slower the return was assumed to fall off with angle, as described in Section 3.0. The azimuthal beamwidth smearing associated with the real aperture of the antenna was again assumed to be the result of a simple averaging, but not along a line in a constant direction. Instead, the averaging took place along an arc with centre at the 'helicopter', and with a radius that was the range being simulated.

Figure 17 is a simulation of a PPI at an altitude of 300 m with a 1 metre antenna . As with the SAR and SLAR, it was assumed that the antenna illumination was adequate to cover the swath from approximately 30° to at least 5°. For operational radars, this is a very reasonable assumption, as a narrow beam, in the vertical dimension, is needed to make the system performance compatible with the helicopter operation. This angle assumption is relatively unimportant in a single sided SAR/SLAR configuration. However, for the PPI, it determines the size of the 'hole' in the centre. At the higher altitudes, this becomes significant. This is apparent in the image shown in Figure 21(antenna length = 1 metre) and Figure 22 (antenna length = 2 metres), where the altitude is assumed at 3000 metres. Although the returns are there from a large area, by the time the near range angle criterion is met, the antenna smearing has already begun to reduce image interpretability.

Figures 19 (antenna length = 1 metre) and Figure 20 (antenna length = 2 metres), show the simulations from 1000 metres altitude. From this altitude, a considerable area of coverage is shown, due to the 360° scan of the antenna. It is proposed that a simple 512X512 display, which would cover the centre 1/4 of the scene, would provide a high quality image, even with the 1 metre antenna.

As with the SAR and SLAR, at 300 metres altitude, the PPI is seriously limited in coverage, due to the falloff at shallow angles. Even with a 1 metre antenna, this effect dominates the azimuthal smear. Unless it is proposed to fly the radar at higher altitudes, the very simplest of radars will provide the majority of the information available.

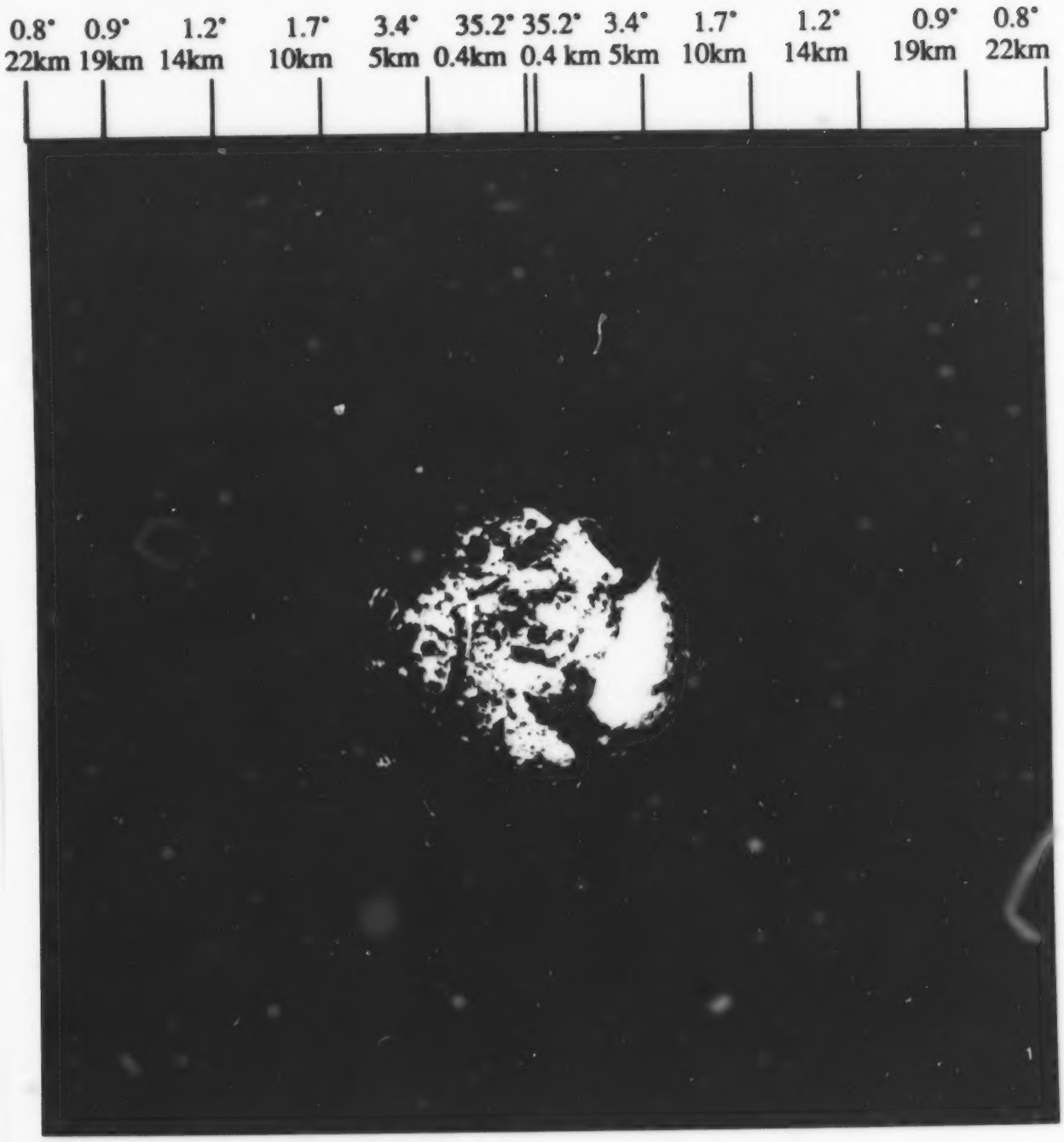


Figure 17 .This simulated PPI image has an assumed antenna length of 1 metre, and a near range incidence angle of 35°. Simulated Altitude = 300 m.

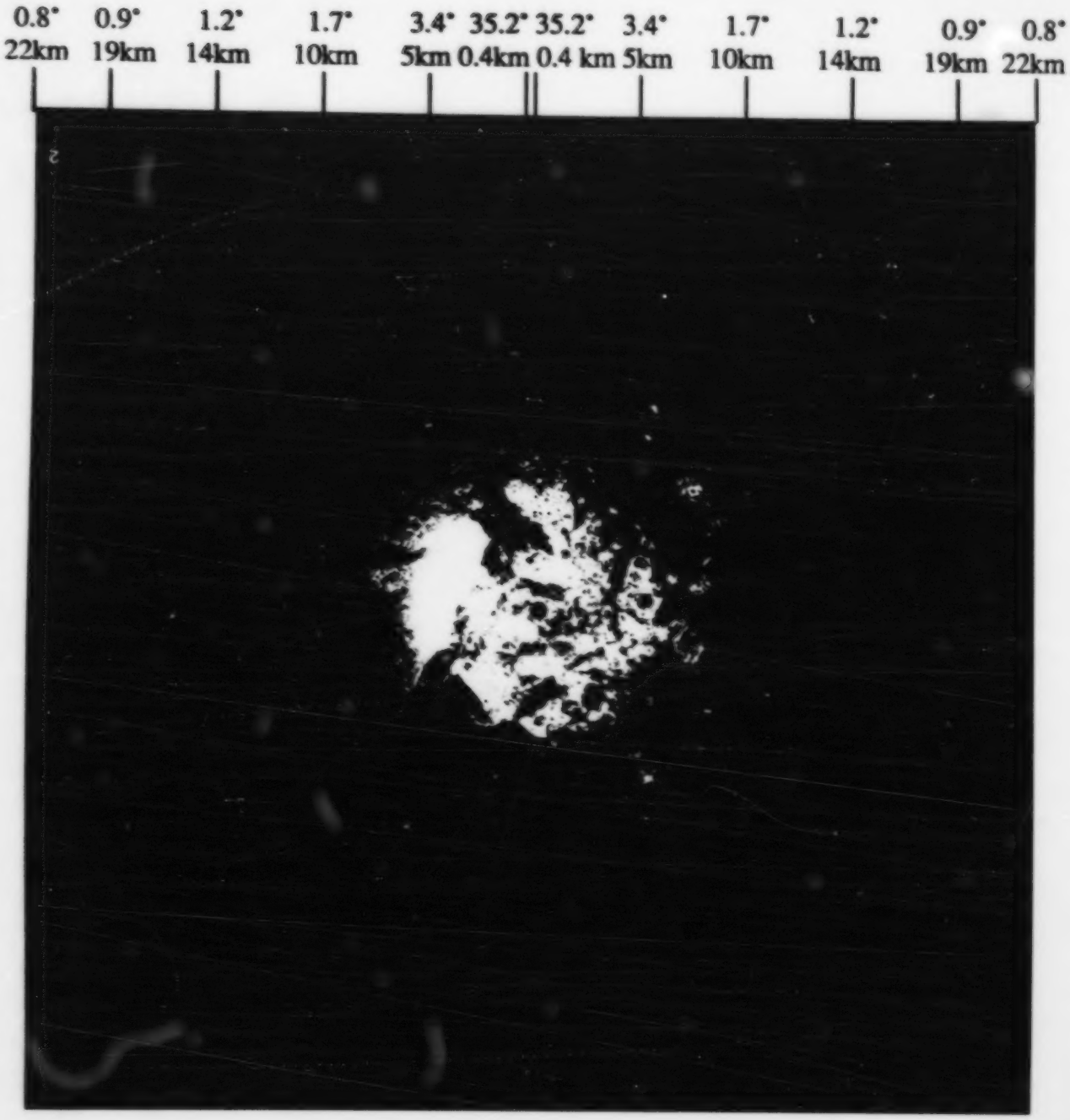


Figure 18. This simulated PPI image has an assumed antenna length of 2 metre, and a near range incidence angle of 35°. Simulated Altitude = 300 m.

Figure 19. This simulated PPI image has an assumed antenna length of 1 metre, and a near range incidence angle of 35°. Simulated Altitude = 1000 m.

Figure 20. This simulated PPI image has an assumed antenna length of 2 metre, and a near range incidence angle of 35°. Simulated Altitude = 1000 m.

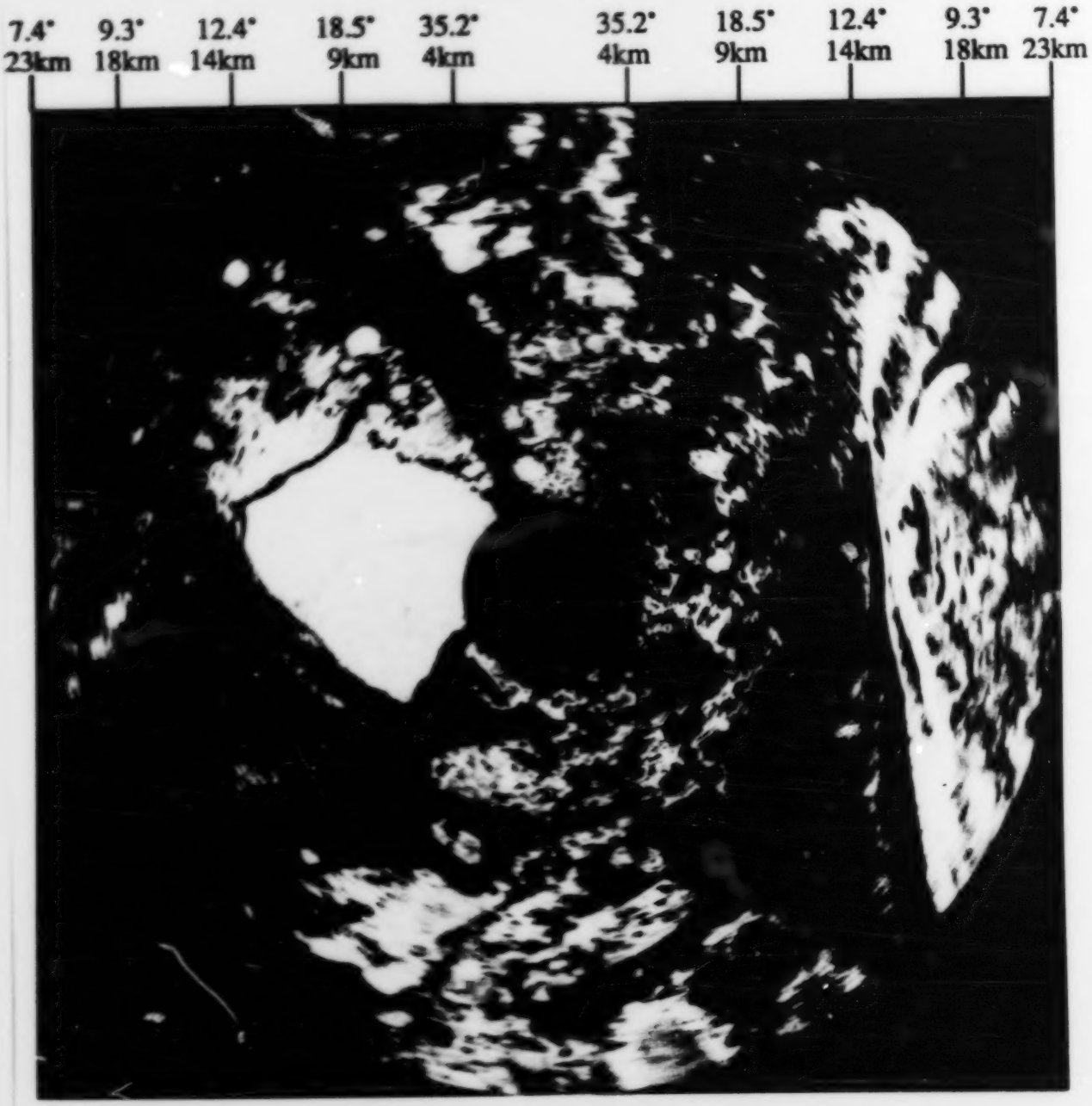


Figure 21. This simulated PPI image has an assumed antenna length of 1 metre, and a near range incidence angle of 35°. Simulated Altitude = 3000 m.

Figure 22. This simulated PPI image has an assumed antenna length of 2 metre, and a near range incidence angle of 35°. Simulated Altitude = 3000 m.

6.0 OBSERVATIONS ON THE SAR SIMULATIONS.

The simulations used are only approximate, and in the absence of a better ice classifier, there will be errors in the treatment of some ice features. However, the overall effects are quite reasonable, and provide a graphic display of the results of flying at lower altitudes. By calibrating the simulation with the SAR data at 1500 m altitude, and with marine radar imagery (not of the same area), a good representative simulation has been obtained.The simulations therefore represent a suitable means of limiting the amount of flying to be done to conduct preliminary tests of the different styles of radars.

Using these data as a basis for discussion, we can make some observations on the potential utility of a helicopter borne SAR. Because the ice reflectivity is such a strong function of angle, the far edges of the image, with a STAR-1 type SAR flown at altitudes of 1000 metres or less, will contain little but information on ridges. Since ridges have their own angle, the angle of incidence between the ice and radar is much less than that for the undeformed ice, and they are quite visible. In some cases, useful information is extracted from ridge only imagery, but it is neither reliable, nor easy to extract without considerable expertise.

One alternate possibility for SAR may arise at some time in the future. The range resolution typical of ice reconnaissance radars is on the order of 5-25 metres. If however a radar with the resolution typical of very sophisticated military reconnaissance systems was used (range resolutions of 1 metre or finer), a case could be made for a much more narrow swath, and as such, shallow angles would not be a factor. However, such radars are extremely expensive for the moment, and are not suitable for the ice reconnaissance role foreseen for the CCG.

6.1 Observations on the SLAR Simulations

Before the simulations started, it was assumed that the fall-off in reflectivity with angle would dominate the utility of the SLAR imagery before the loss of along track resolution, for some antenna lengths, at some altitudes. The question was to establish the altitude, and antenna length compromise which was most appropriate for the helicopter application. Since both the altitude and the antenna length have distinct practical limits, only a subset of possible parameters was examined. Examples of SLAR imagery, simulated from the SAR data collected at 1500m altitude a re shown in Figures 23, 24 and 25. As can be seen from these data, the limitations of azimuth resolution and the fall-off in reflectivity are similar for the 3 metre antenna image, but the azimuth smear is the limiting element for the two shorter antennas.

For an altitude of 300 m, the reflectivity fall-off clearly dominated, and even for an antenna length of 1 metre, the SLAR imagery was not seriously degraded in utility over the SAR data. For an altitude of 3000 metres, the azimuth smearing was always apparent. At an altitude of 1000 metres, both the 1 and 2 metre antennas showed azimuth smearing dominated before the loss of reflectivity. With a antenna 3 metres, as shown above, the two effects are both present, and a usable swath width of 10-15 km can be obtained. For a helicopter that will not likely be more than 100 km from its ship, this is not a serious limitation.

We have further simulated this effect by a study of the actual data collected at 1500 metres, with the radar in the fine resolution mode. The radiometric properties of this imagery is real, in so far as they were not modified by the simulation process. The along track resolution of the imagery has a simulated antenna length of 1, 2 or 3 metres in Figures 23, 24 and 25 respectively. Again from these data it can be seen that the roll of in information

content due to azimuthal resolution dominates for all antenna lengths but 3 metres. From this we gain confidence in the conclusions drawn from the detailed simulations.

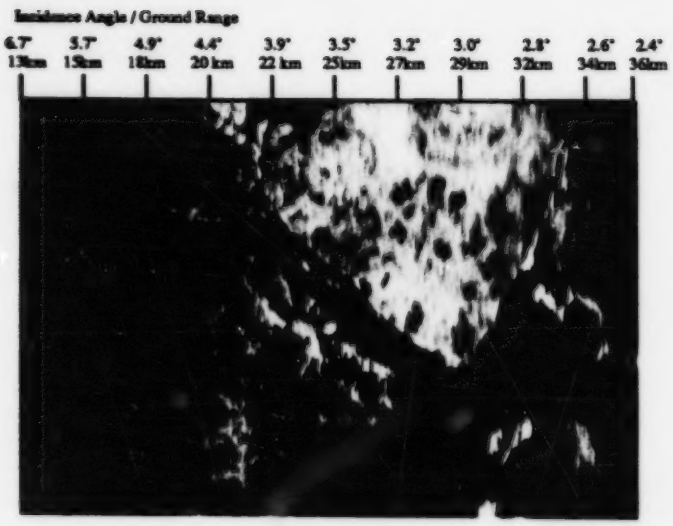


Figure 23. SLAR imagery simulated from collected SAR data, 1500m altitude. 1 metre antenna.

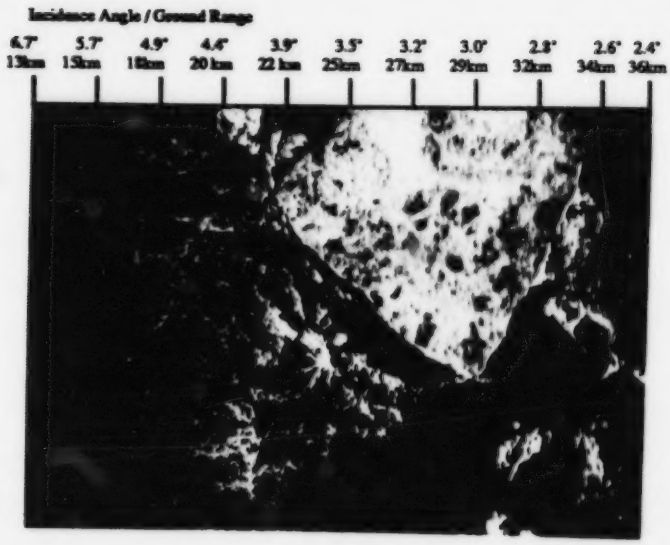


Figure 24. SLAR imagery simulated from collected SAR data, 1500m altitude. 2 metre antenna.

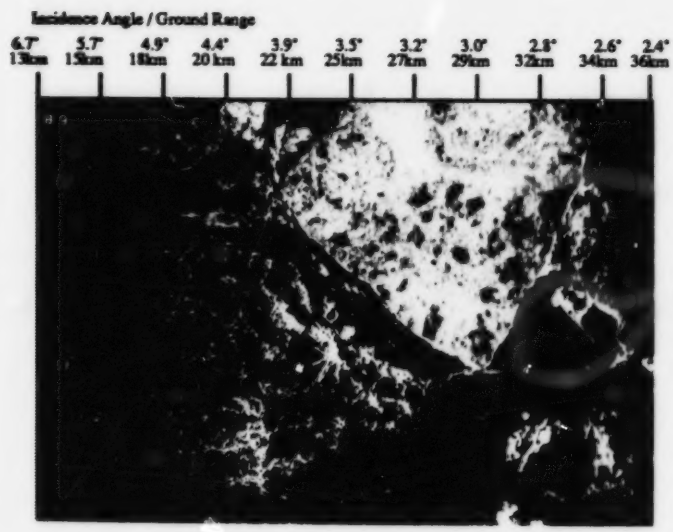


Figure 25. SLAR imagery simulated from collected SAR data, 1500m altitude. 3 metre antenna.

6.2 Observations on the PPI Simulations

With an altitude of 3000 m, it was observed that the azimuthal smearing always inhibited the image utility, unless the unwieldy 2 m antenna was used. At 1000 m altitude, the 1 m antenna produced a usable range of 5-10 km, but over a full 360° around the craft. This area coverage gives an enhanced impression of the image utility, by, in effect doubling the area coverage compared to a single sided SLAR. Further, a PPI type radar covers the 'hole' under the aircraft by looking fore and aft.

PPI style radars can be used on the helicopter for ice reconnaissance, and for a number of other tasks such as navigation and search and rescue. Since this is beyond the scope of the current study to address all these operational considerations, it is left to the CCG to consider which radar best suits their needs.

6.3 Overall Observations on the Simulations

In the course of this study we have examined the relative image quality of helicopter borne SAR, SLAR, and PPI radars. It has been shown that the SAR, while it demonstrates very real increases in image quality at longer ranges, does so only at higher altitudes. For helicopters that are restricted in altitude, and for the relatively narrow swath widths associated with close range tactical reconnaissance, this is not a significant advantage. It is therefore concluded that either a SLAR or PPI radar would be adequate for this task. Further, given that SAR systems are more complex, heavy and much more costly that the other two types of radars, we would recommend against them, unless other criteria, not considered in this study are brought to bear.

Of the two alternatives, SLAR and PPI, it is not currently possible to definitively declare one superior to the other, as the operational scenario against which they are to be judged is not sufficiently well defined. With SLAR, the continuous strip imagery is very compatible with the current STAR-VUE operation, which receives the SAR from the CIRS and the SLAR from the Dash-7 aircraft. However, the PPI radar is compatible with the standard PPI of the ships radar, and could easily be made to fit into the display system of STAR-VUE.

The simplest of the two radars to install, by a fair factor, is the PPI radar, as it uses a shorter antenna, and has much less of a requirement for the flight path of the helicopter to be stabilized. Further, it would be possible to use the PPI radar as a source of navigation data for the helicopter. It is therefore recommended that a radar of this type be placed aboard a CCG icebreakers helicopter, and that experiments be conducted to determine the exact requirements for such a system. It is probable that operational details of the system, as used by the CCG will dominate the consideration of the utility, so that no amount of paper study will be able to address the question of what is required of such a system. In the following section we will outline an experimental program that will identify the key issues for CCG in defining a helicopter based radar for ice reconnaissance.

7.0 PROPOSED EXPERIMENTAL SYSTEM

To support the operation of the CCG Ice breakers, helicopter ice reconnaissance missions are often flown with the ships support helicopter. To improve the quantity and quality of information available to the ice breaker crew, it has been proposed to put reconnaissance systems on the helicopter and telemeter the data back to the ship. A previous study by Ramseier concluded that the optimal sensor would be a microwave imaging system, based on either passive or active technologies. This study addressed the optimum type of active sensor to place on a helicopter, but did not consider passive sensors.

The original requirement for a helicopter system was that it have an information content similar to the STAR-1 data. This rather loose requirement was sufficient for this study, but does not address the problem of specifying a radar to be purchased and installed on CCG helicopters; a considerable expense. Further, the requirements as perceived by the CCG have to date been developed in an operational environment that did not include direct SAR support. In mid August 1989, the dual sided SAR system aboard the Challenger 600 jet began regular ice reconnaissance. All active CCG icebreakers are equipped with downlink receivers and workstations (STARVUE) to allow the crew direct access to those data.

The requirements are further complicated because the ships crews have begun to work with the SAR imagery, and are confronted with handling the data in a Geographical Information System (GIS). For the ship there are really two frames of reference, that of the ice and the absolute or map reference. In order to relate one to the other, there is a requirement for real time ice information that can be used to measure ice motion. This can come from either the ships radar, or the helicopter radar. Both are capable of providing a geographically registered image that can provide a reference to allow tracking of the motion of the ice between the time a SAR mosaic was taken and the present time. (A new dimension may also be added to this problem when the EM ice thickness sensor becomes available. These data must be accurately placed on the SAR mosaic, and not the absolute reference plane, in order to allow the ships crew to accurately use the ice thickness information in planning the ships passage.)

To accurately assess the requirements it would appear to be necessary to actually install a radar on a helicopter, and to fly it in the arctic, from a ship equipped with a STAR-VUE. A preliminary design of such a system has been done, and a costing exercise indicates that it could be done in a reasonable fashion. The result of that preliminary design is given in this section. It lays out the main elements of the program and a schedule that is felt both reasonable and achievable that will result in a system being tested in the Arctic.

8.0 PROPOSED SYSTEM DESCRIPTION

INTERA has discussed the question of radar availability with numerous radar manufacturers, and has concluded that, at least for the purposes of this experiment, MARCONI has the best available system. Their system is currently flying on some 120 US Coast Guard helicopter, and therefore is clearly able to be used in this role. Further, MARCONI have expressed a willingness to rent a radar to such a project at a reasonable cost. The system proposed has a range resolution of 16 metres, and can be fitted with either a 91 cm rotating antenna, or a 4.2 metre fixed, side looking antenna. Further, MARCONI have agreed to provide the system with a Low Noise Amplifier (LNA), and a log video amplifier.

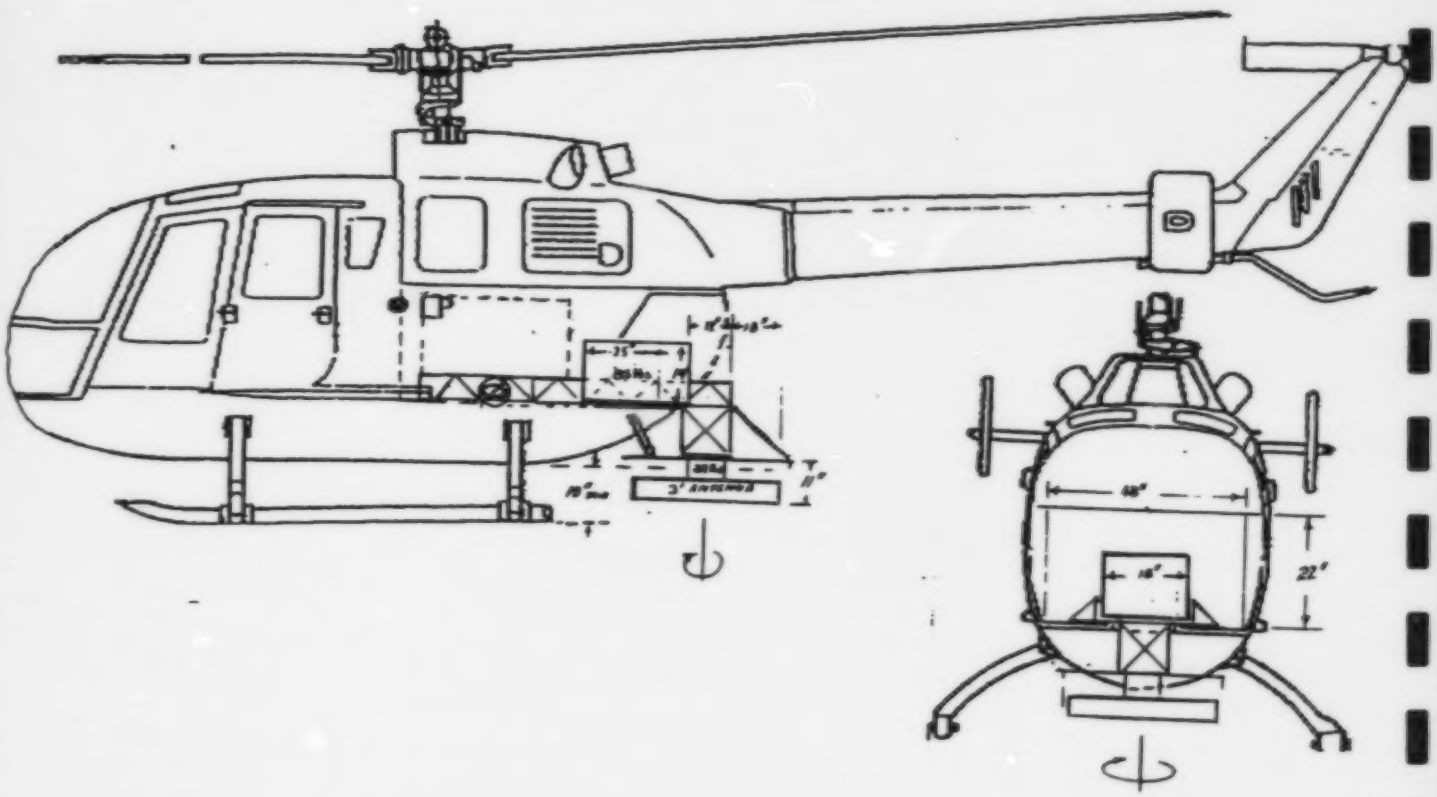
INTERA has discussed the problem of mounting the radar on the CCG BO105CBS helicopters with various people at the CCG and a planned installation has been evolved. This will consist of a tray mounted assembly that will fit into the tail end of the helicopter, and hang the rotating antenna out back of the helicopter. A sketch of the arrangement has been shown in Figure 26. It will be very easy to install and remove the equipment from the equipment rails in the cargo hold. An estimate of the cost of the frame needed to hold the radar has been made and it would appear to be quite reasonable. It could possibly prove that the installation would have more lasting value than just for this experiment.

The installation of a downlink on the helicopter could easily be undertaken by INTERA, using equipment previously used on the STAR-1 system in the Beaufort Sea. While there will be some need to modify the system to be compatible with both the MARCONI radar, and the new STAR-VUE purchased by CCG, this will be a small expense, relative to the cost of a new downlink.

INTERA proposes to place a Folsom Scan Converter currently owned by TDC (or the identical system from CCIW), aboard the selected CCG vessel, and to integrate the display of the rotating radar aboard the helicopter into the operation of the ice information management system aboard the ship, in much the same way that the shipborne radar data were integrated in the MARINE-VUE system. When the system is operating in the SLAR mode, the data will be displayed on the STAR-VUE.

Figure 27 shows a block diagram of the proposed experimental layout. Virtually all of the equipment is off-the-shelf hardware. The only exception is the mounting rack that is used to install the radar into the helicopter. The equipment availability is as shown in Figure 28.

Figure 26. A Sketch of the Proposed Radar Installation on a CCG Helicopter. It is proposed to build a tray that would mount on the equipment rails, and allow the antenna to protrude from the rear of the helicopter. In this way, a quickly removed installation can be achieved, that will be entirely self contained, with the exception of the pilots display, and the operator console, which can each be connected with a single cable.



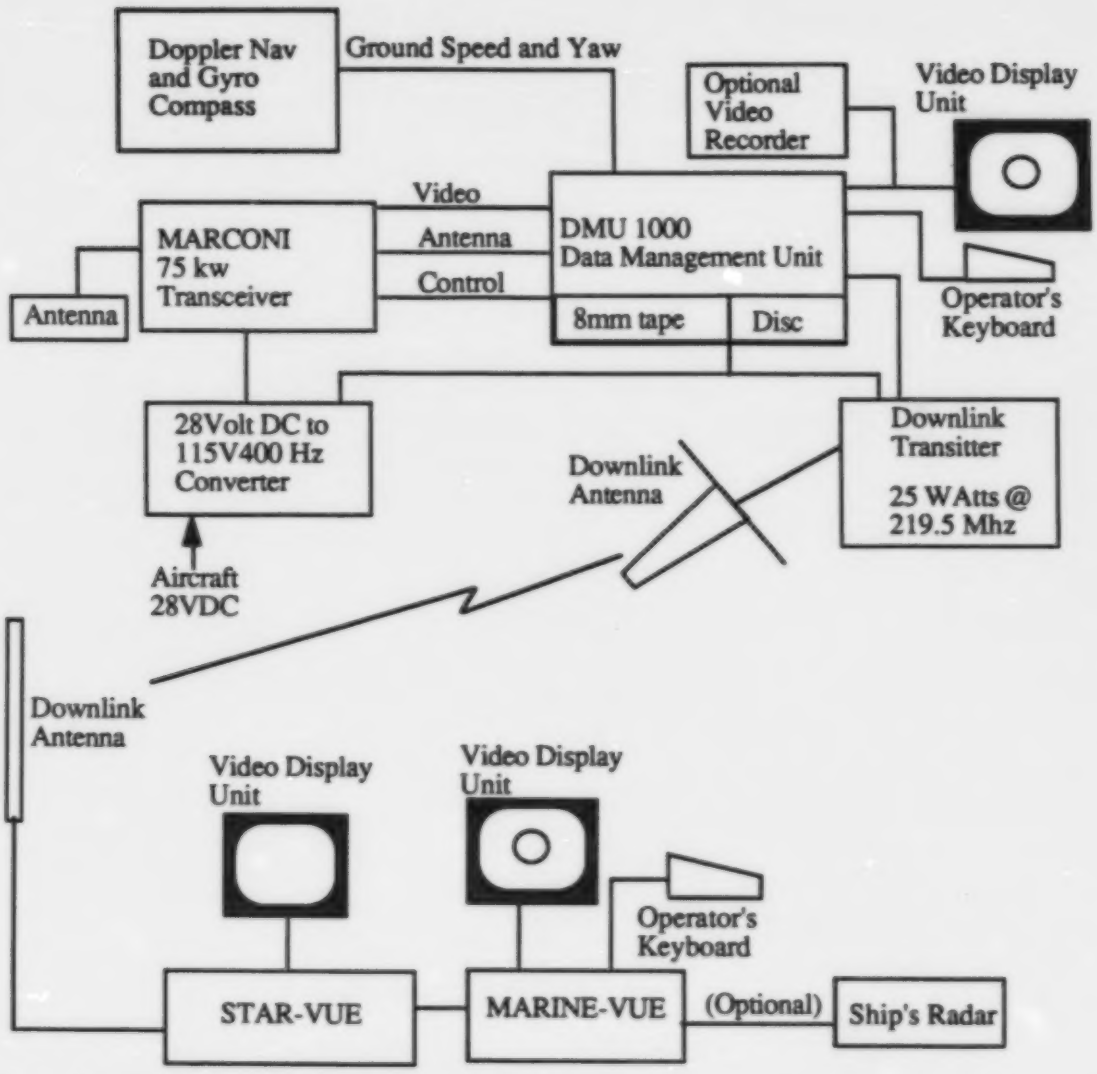


Figure 27. The Proposed Helicopter Radar Installation
The radar antenna will be either the 91cm rotating antenna, or the 4.2 metre fixed, side looking antenna, depending on which experiment is being run. No motion compensation system is planned, as this would require an interface to the helicopter's navigation system.

Figure 28. Equipment Proposed for This Experiment

Equipment	Source	Availability
MARCONI Transceiver	Canadian MARCONI	Off the shelf
91cm antenna	Canadian MARCONI	Off the shelf
4.2 meter antenna	Canadian MARCONI	Off the shelf
DMU 1000	INTERA Technologies	Minor Software Mods Required
Downlink transmitter	INTERA Technologies	Off the shelf
Downlink antenna	INTERA Technologies	Off the Shelf
28V-115V Converter	INTERA Technologies	Off the shelf
Shipboard 219.5 antenna	INTERA Technologies	Off the shelf
STAR-VUE	Installed on CCG Ship	Software Additions Required
MARINE-VUE	CCIW or TDC	Off the shelf
Mounting Rack	Hardware Subcontractor	To Be Fabricated

9.0 ESTIMATED WORK REQUIRED TO CONDUCT THE FIELD TESTS

Task 1 Helicopter Installation

Design and have approved a rack for the installation of the equipment in the back end on the CCG 105 Helicopter. For this task it is assumed that CCG will make available a helicopter and appropriate power (28 V DC) in either Montréal or Ottawa for a trial installation. It is also assumed that CCG engineers will be available and will assist in obtaining the needed approvals for this installation.

Task 2 Radar Preparation

Sub-contract with Canadian MARCONI to provide a 75kw radar in a form suitable for installation aboard the CCG Helicopter. This will include the provision of both Log Video, and a Low Noise Amplifier as additions to the basic radar.

Task 3 Data Management Unit (DMU 1000) Preparation

The DMU 1000 will be configured to receive and process the radar data from the MARCONI Radar System. This will include a control function for the radar, as well as the provision of an on-helicopter display. Data will be recorded both on disc and on 8 mm tape. The STAR-VUE

Task 4 Shipboard Installation and De-installation

Configure aboard the ship a 219.5 antenna, and receiver system, with the cooperation of CCG. There will also be a need to install modified software in the STAR-VUE system to allow the reception of data from the rotating radar, and its transmission to the MARINE-VUE system, or direct display, as appropriate. The equipment will returned to the appropriate location and condition at the end of the experiment.

Task 5 Shipboard Operation

To ensure the optimum data set is acquired, and that the appropriate questions are answered, a carefully designed and conducted experiment must be conducted. In addition to the proper operation of the data collection equipment, it is important that the appropriate interactions be observed between the CCG crew on the ship, and the data as made available. It is our opinion that tailoring the system to the exact needs of the CCG will be a difficult task because the requirements need to be developed as part of this study.

Task 6 Data analysis reporting

Ensure that the experimental results are fully analysed, and that the CCG requirements are well defined in a report to be completed after the end of the voyage.

9.1 PRELIMINARY PRICE PROPOSAL

A preliminary analysis of the cost of the project has been conducted and it is felt it could be completed for a cost of between $250,000 and $300,000. As this is a preliminary pricing, there is considerable contingency in the figure. If there is an interest in this project, INTERA would be prepared to generate a full proposal to conduct this study.

10.0 CONCLUSIONS AND OBSERVATIONS

The simulations conducted would indicate that a SLAR or PPI type radar, with characteristics similar to currently available units could provide a local ice reconnaissance capability that would, for the altitudes typical of ship based-helicopters, be of similar value to SAR imagery. For example either a 1 metre rotating antenna, or a 3 metre fixed SLAR, operated at 1000 metres altitude can provide an image with good interpretability over a swath of 15 km. Such a radar is available from several manufacturers such as Marconi.

The Marconi LN66HP radar set is representative of the type of radar that can be used for a helicopter borne radar, either in a SLAR or PPI mode. A preliminary investigation of an installation of this radar aboard an MBB BO 105 helicopter has been conducted, and is described in this report. This installation would weigh on the order of 100 kg, and would have resolution similar to or slightly better than the imagery shown in this simulation from the SLAR 3 metre antenna or the PPI with the 1 metre antenna.

11.0 REFERENCES

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